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INDUSTRIAL NOISE - A GUIDE TO ITS EVALUA-
TION AND CONTROL

Andrew D. Hosey, et al

National Center for Urban and Industrial Health
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and control

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U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

Public Health Service



INDUSTRIAL NOISE

A GUIDE TO ITS EVALUATION AND CONTROL

Edited by:

Andrew D. Hoesy
Charles H. Powell, Sc.D.

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Bureau of Disease Prevention and Environmental Control
National Center for Urban and Industrial Health
Occupational Health Program

I

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PREFACE

The awareness of noise exposure as a potential hazard to the hearing of man is neither recent nor contemporary. However, the scope of this problem has not been fully appreciated until recent years. In realization of the fact that the hazards of noise exposure are of increasing significance due to the escalating production of noise by our technological society, people in the field of occupational health are seeking to learn more about this invisible but audible hazard.

In recognition of this problem the occupational health program of the Public Health Service has presented special courses on industrial noise since 1961.

This manual presents lecture outlines and reference materials developed for use in two one-week training courses in

industrial noise for industrial hygienists.

Designed to supplement instruction offered in the training courses, Industrial Noise and Noise Control, the manual will also be made available to industrial hygienists not attending the course for a guide and general reference.

The courses upon which this manual is based do not attempt to cover the entire subject of industrial noise. They are designed to instruct engineers and industrial hygienists new to the field of occupational health the basic procedures and techniques of recognition, evaluation, and control of noise in the work situation, and to give more experienced professionals an opportunity to review these fundamentals and to exchange experiences and information.

Cincinnati, Ohio

May 1967

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RUDIMENTS OF EVALUATING EXPOSURES TO NOISE

Introduction

General principles used for evaluating occupational exposures to noise are no different from those used for an overall evaluation of the occupational environment. For guidance on the latter the reader is referred to Section B-1 of the "Syllabus".⁽¹⁾ However, for this particular course on industrial noise it was considered appropriate to include in the course manual a discussion on this subject with special emphasis on noise.

The late Dr. Charles R. Williams⁽²⁾ appropriately summarized some of the problems and pitfalls encountered by industrial hygienists in this area when he stated: "Questions related to an evaluation of the work place must, of course, be answered on the basis of what we know about man and his physiological response to his environment. Some of our difficulties in the past have been related to a gap between knowledge of physiological effects and the selection of proper sampling techniques. Throughout the history of industrial hygiene, the basic approach to controlling occupational disease has consisted of an evaluation of potential hazard and control of such hazard by engineering or medical techniques. Decisions as to whether a hazard exists have been based on comparing data collected in the industrial environment with hygienic guides, threshold limit values, or maximal accepted concentrations. Our heavy dependence on such values, regardless of their validity, has given us, in several instances, a false sense of security. In some cases, we have sacrificed progress because of a reluctance to abandon the past. This attitude may well continue to plague us in the future, unless we recognize its basic fallacy and take steps to eliminate it"

Prepared by: Andrew D. Hosey

The purpose of this discussion is, therefore, to suggest guidelines to assist those industrial hygienists whose function may include the evaluation of occupational noise exposures.

What is Noise?

A simple definition of noise is unwanted sound, but noise has a different meaning for the several specialists engaged in this field. "To the physicist, noise is a sound, whose character can be defined and whose properties can be measured with the same equipment that measures other sounds. To the psychologist, who is also interested in all types of sounds, noise is an undesired sound, as contrasted with music and speech, which are usually desired sounds. Whenever we study the effects of physical phenomena on human beings, we are working in a field where the interests of the psychologist and those of the physicist overlap. The result is usually a happy collaboration, and in no field has this collaboration been more fruitful than in the measurement and evaluation of the effect of noise."⁽³⁾ A more detailed discussion concerning the connotation of sound and noise is given in Section N-2 of this manual.

It is difficult to believe now, but "It took nearly fifty years of exposure to noise in industry before it was recognized as a hazard. It was known that noise produced hearing loss, but no attempts were made to control it. Once the incentive was provided, in the form of compensation, needed instrumentation began to be developed. We are, however, still struggling with attempts to understand the significance of measurements now being made When these and other questions have been answered, it will be possible to provide measurement systems which will obtain valid information on industrial noise exposures...."⁽²⁾

Preliminary Survey

Before any attempt is made by the industrial hygienist, or other qualified person, to evaluate occupational noise exposures, it is essential that he be able to recognize the sources of potentially hazardous noise. Furthermore, the investigator should determine the number of workers exposed, types of control or protective measures employed, and other factors relating to the problem at hand. Much of the above information can be obtained, and valuable time saved, by conducting a preliminary survey of the plant or of specific operations. The importance of taking adequate notes during a preliminary survey or study cannot be overemphasized.

Many individuals, who have a "well-trained ear," can detect those operations or areas of a plant where sound levels are of sufficient intensity to interfere with speech (about 85 dB). Indeed, a good rule of thumb in judging the presence of excessive noise is whether you have to shout in order for a nearby person to hear what you are saying. Thus, a walk through the plant can serve to identify areas where there are noise problems. However, if an adequate screening survey is desired, the human ear cannot be relied upon and a great many noise sources must be reviewed, usually in a brief period of time. To accomplish this some type of highly portable equipment should be used. Several sound survey meters are available for this purpose, or the investigator may prefer to use one of several light-weight sound level meters. In any event, the purpose of a preliminary or screening survey is to locate sources of noise with levels of about 85 dB or higher. These areas or locations can then be studied in more detail by the use of sound level meters, octave band analyzers, or other equipment at a later time. It should be emphasized here that sound survey meters do not usually meet the American Standards Association (ASA) specifications for sound level meters. Nevertheless, sound

survey meters are quite acceptable for obtaining first approximations to noise conditions. Naturally, these instruments must be calibrated prior to their use and periodically during a survey (depending upon the type of instrument and the manner in which it is used and transported during the survey).

Several forms have been devised to record data obtained during a screening survey. Three such forms are shown in Figures 4.1, 4.2, and 4.3 of Industrial Noise. (4) Use of these, or similar forms, will facilitate the recording of pertinent information which will be extremely useful if more detailed studies are to be conducted later.

A more detailed discussion on screening surveys appears in Section N-7 of this manual and in Chapter 4 of the Industrial Noise Manual.

Evaluation of Noise Exposure

Evaluation of occupational noise exposures requires a teamwork approach similar to that used for evaluating the occupational environment in general. Depending upon the nature and extent of the situation, the services of engineers, physicists, physiologists, physicians, and others may be needed to solve a particular noise problem. Although engineers or physicists generally conduct the environmental study and collect data to define the degree of exposure, other specialists are needed to determine whether a worker has, or may possibly develop, a loss of hearing and to what extent, and to advise on corrective or preventive measures.

Much useful information should have been obtained during the preliminary survey. This should include:

- (1) noise sources or areas to be studied,
- (2) number of persons exposed and duration,
- (3) characteristics of noise steady wide-band, steady narrow-band, or impulse, and
- (4) description of the acoustical environment.

After the above minimum information is obtained, the next step is to secure noise level measurements, octave band analyses, and other data as indicated.

Conducting the Study

It is not the purpose of this discussion to go into detail regarding procedures and equipment to be used but rather, to cover several general considerations that should be followed in making a noise study. Details on procedure and equipment are given in this manual and in references (3) and (4).

The first important decision to be made by the investigator is to determine the location or locations where measurements will be made. This choice depends primarily on the purpose of the particular study. Usually, the problem is to determine whether or not a worker or a group of workers is being exposed to noise levels that may cause an impairment in their hearing, either temporary or permanent. In this situation, measurements must be made wherever a worker spends a portion of his work day so that results can be compared with noise criteria. If the worker spends most of his day operating a punch press, for example, then representative measurements must be made that will represent his exposure while operating the press. In addition, if the worker spends a few hours at some other location or in a less noisy area, measurements must be made there also.

If, on the other hand, the purpose of the study is to determine which machine or parts of a machine create the most noise, then measurements are made in the area immediately adjacent to the machine. In this situation, where data are usually desired for control purposes, the investigator need not be concerned with the worker.

The next decision concerns the period of time over which measurements should be made. This depends upon several factors. Among them are the characteristics of

the noise and the duration of the operation. If the noise is steady and the operation(s) is continuous, a minimum of three measurements should be made. These should be of sufficient duration to obtain the desired data. Data thus obtained should be representative of the workers' exposures. Conversely, if the machine or operation produces an impulse-type noise, measurements should be made periodically throughout each of about three non-consecutive days. This procedure is another attempt to provide representative data.

Finally, if the plant operates more than one shift, it may be necessary to make noise measurements during each shift. Depending upon the particular plant and type of operations, noise levels and the distribution of energy with frequency could be different on each shift. A similar situation existed during a heat-stress study where it was found to be hotter during the second shift (3:00 to 11:00 p.m.) than it was in the daytime even though operations were identical during each shift.

There is no "cook book" procedure available that covers the selection of sampling sites, or suggests the number of measurements to be made. Decisions on these questions have to be based upon the experience and judgment of the individual conducting the study. The object, however, is to obtain data that are truly representative so that the workers' exposure can be evaluated.

Choice of Equipment

Section N-6 of this manual includes a brief description of several types of instruments and accessories that are usually employed in making noise measurements. Other information on equipment appears in references (3) and (4) and in other literature sources, including brochures or manuals supplied by many manufacturers. In this introductory section, however, there are several items that should be emphasized.

Results obtained during a survey or detailed study are meaningless unless the investigator is familiar with and follows proper procedures. He must know how to operate each instrument and be aware of its limitations. Furthermore, he needs to know which instrument will provide reliable data for the particular problem in question. Thus, considerable time should be spent by the investigator reading operating instructions and using the various instruments. All too often "experts" in this field fail to observe these simple precautions with embarrassing results, which are quite obvious to those with more experience.

Interpretation of Results

After all measurements have been made and other necessary data have been assembled, the final step in the evaluation is to interpret results. In some instances it may be necessary to compare results with noise criteria or standards. This, it should be pointed out, is often no simple task, but guide lines on this subject are given in Section N-5. In order to use these criteria wisely it is necessary for the investigator to understand the physics of noise and its physiological and psychological effects. At this point, then, the investigator should consult with others to assist him in the interpretation and application of these standards. It should be emphasized, however, that a great deal of sensible

judgment is necessary in this step of the evaluation.

In other cases where State regulations or standards have been adopted, as in California⁽⁵⁾, it is necessary only to compare noise levels at certain frequency ranges with these standards. If noise levels are less than those permitted, no further action is indicated. On the other hand, if results exceed levels permitted, then a decision must be made on procedures to reduce the workers' exposure. This entails, preferably, the use of engineering control methods to reduce the noise at its source or, if this is not feasible, the use of ear protective devices. Discussions on each of these techniques are given in Sections N-10, N-11, and N-12. Here again, common sense should be exercised in making recommendations.

Finally, if the problem at hand requires a decision regarding hearing loss, information will be needed in addition to data on noise level and frequency analysis, characteristics of the noise, and duration of exposure. It becomes necessary through audiometry to determine whether or not the hearing of workers is being affected adversely. The team approach, referred to earlier in this discussion, is necessary in evaluating data and rendering decisions in this facet of the problem. An excellent discussion on audiometry appears in Section N-9.

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Introduction

Sound is defined by the United States of America Standards Institute (USASI) (formerly the American Standards Association) as an oscillation in pressure, stress, particle displacement, particle velocity, etc. in a medium with internal forces (e.g., elasticity, viscosity) or the superposition of such propagated oscillations, or as an auditory sensation evoked by the oscillations described above. The term "sound wave" could be used for the first concept, and "sound sensation" for the second concept.

Airborne sound refers to rapid pressure variations; that is, alternate increases and decreases in normal atmospheric pressure produced by a vibrating object or turbulence within the air. Two of the various characteristics that distinguish one sound from another are loudness and pitch. Loudness is a measure of the quantity of sound that reaches the listener's ear. Pitch is a measure of the quality of a pure tone. Some sounds are pure tones and others a combination of several tones, but many sounds are neither. Instead they can be described as "broad band" sounds. Even without distinctive tones the sounds may have a characteristic quality that identifies the source to the average listener.

Noise is defined by the USASI as any undesired sound. This may be a pure tone, a combination of pure tones, or a broad band of sound that is undesired at a particular location at a particular time.

Frequency and Speed of Sound

The generation of sound is probably most easily described by using a vibrating object as the source. While the vibrating object is moving in one direction, there is a buildup of pressure as the air molecules are pushed together, which continues until the object reverses direction. This region of higher pressure is a pressure wave which moves out in all directions from the object. As the object moves in the opposite direction, the air molecules move further apart and a region of reduced pressure is created. This region of reduced pressure is forced out from the vibrating object by the next pressure wave. As the vibration continues, waves of increased and decreased pressures are set up. One complete vibration of the object corresponds to one complete cycle of pressure change. The number of object vibrations or pressure cycles per unit time defines the frequency (pitch) of the sound wave, and this is usually expressed in cycles per second (cps).

The speed with which sound waves travel is a function of the elasticity of the air and its density. The elasticity of the air is equal to a constant times the static pressure of the air, i.e., atmospheric pressure. The constant is equal to the ratio of the specific heat of air at constant pressure to the specific heat at constant volume, which at the temperatures normally encountered would be equal to 1.4. Thus the speed of sound (c) can be computed from the equation

$$c = \sqrt{\frac{1.4 P_0}{\rho_0}}$$

where P_0 = atmospheric pressure
 ρ_0 = the density of the air

If the assumption is made that the air behaves as an ideal gas, which is a reasonable assumption for most tempera-

Prepared by: Herbert H. Jones

tures and densities normally encountered, it can be shown that the speed of sound is dependent only on the absolute temperature of the air.

The equation for the speed of sound in feet per second is

$$c = 49.03 \sqrt{R} \text{ ft/sec.}$$

where R = the temperature in degrees Rankine, i.e., 459.7° plus the temperature in degrees Fahrenheit. The speed of sound in air at 70°F is 1,128 ft/sec.

The distance that a sound wave travels in one period or cycle is called the wavelength of the sound. Thus the wavelength is given by the equation:

$$\lambda = \frac{c}{f}$$

where c = speed, ft/sec.
 f = frequency, cps
 λ = wavelength, ft.

The wavelength of a 100 cps wave is 11.28 feet when the speed of sound is 1,128 ft/sec. All frequencies travel at the same speed in a particular medium; therefore, wavelength varies with frequencies.

Units of Measurement Expressing Quantity of Sound

In the discussion on the generation of sound waves it was pointed out that these waves travel away from the vibrating object in all directions in the form of spherical waves. These waves will continue to travel until they are absorbed by the air or reflected by some object. If there were no air absorption, then all of the acoustic power radiated by the source would pass through any surface that completely encloses the source; e.g., the surface of an imaginary sphere of air. The acoustic power passing through a unit surface area decreases as the distance from the source

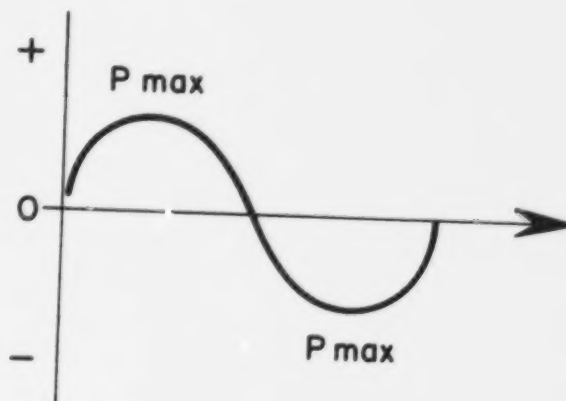
increases. This power passing through a unit area is a measure of the intensity of the sound.

In a free-field, one with no obstructions to the flow of sound waves in all directions, the intensity is the same at every point on a surface at equal distance from the source. Therefore, total power (W) can be computed from the equation

$$W = IS$$

where I = intensity, watts/sq ft.
 S = surface area, sq ft

It is difficult to measure sound intensity directly. Most acoustical instruments are designed to measure effective sound pressure or square root of mean-square sound pressure. The square root of mean-square sound pressure can be defined as follows:



$$P_{rms} = \sqrt{(0.5 P_{max})^2 + (-0.5 P_{max})^2}$$

$$= \sqrt{0.25 P_{max}^2 + 0.25 P_{max}^2}$$

$$= \sqrt{0.5 P_{max}^2} = \sqrt{\frac{P_{max}^2}{2}}$$

$$P_{rms} = \frac{P_{max}}{\sqrt{2}} = 0.707 P_{max}$$

Thus, sound pressure is related directly to sound intensity. For spherical waves intensity (I) is computed as follows:

$$W = I_{\text{avg}} 4 \pi r^2 \text{ watts}$$

$$I = \frac{p^2}{\rho c} \text{ watts/unit area}$$

where p^2 = mean-square sound pressure

ρ = density of air

c = speed of sound in air

The sound power (W) of the source can then be computed from the equation:

where I_{avg} is the average sound intensity at a distance r from a sound source whose acoustical power is W as shown in Figure 1. The quantity $4 \pi r^2$ is the area of the sphere over the surface of which the intensity is averaged. From this relationship it is obvious that the intensity will decrease with the square of the distance from the source, the well-known inverse-square law.

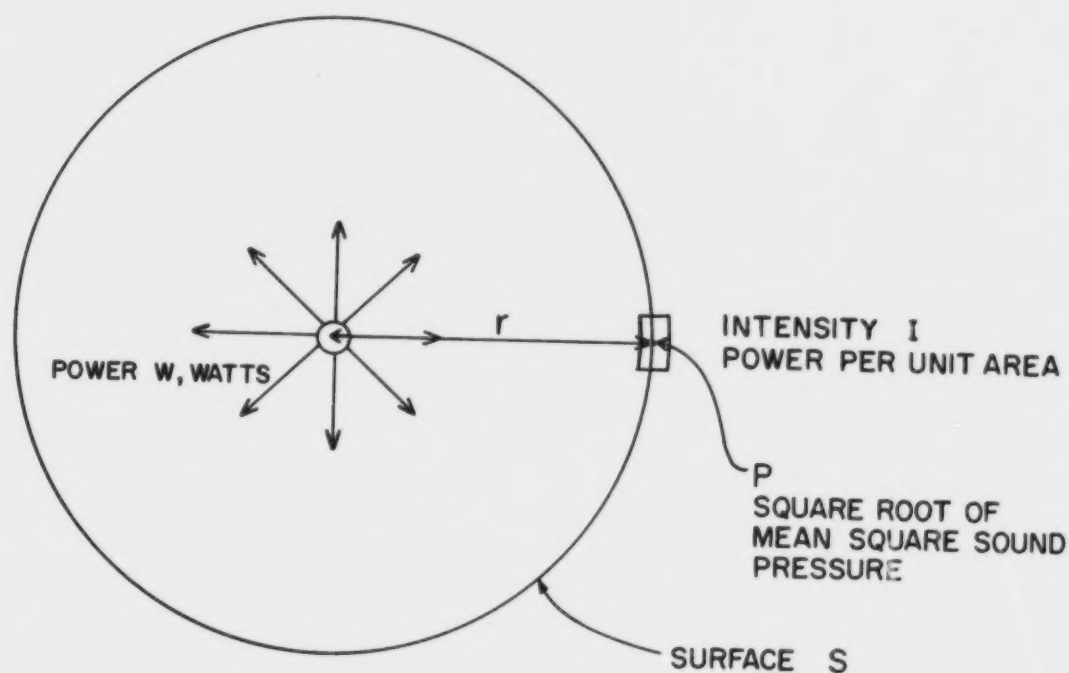


Figure 1. A single nondirectional sound source radiating W watts producing a sound intensity I in watts per unit area.

Selecting a practical scale for noise measurement involves two problems. The first is caused by the tremendous range of sound power or pressures that is encountered, i.e., from 0.0002 microbar (a microbar is about one millionth of an atmosphere, or specifically 1.0 dyne/cm²) at the threshold of hearing under ideal conditions to 10,000 to 100,000 microbars for noises associated with jet or rocket propulsion systems. The second problem arises from the non-linear manner in which the ear responds. The ear tends to respond logarithmically to the intensity of an acoustical stimulus.

Both of these problems can be solved by the use of the decibel (dB), a unit commonly used to express power or voltage levels. By definition, the decibel is a dimensionless unit used to express the logarithm of the ratio of a measured quantity to a reference quantity. In this way the dB is commonly used to describe levels of acoustic power, intensity, and pressure.

Most sound-measuring instruments are designed to respond to sound pressure changes and are calibrated to read in terms of the logarithm of the ratio of the root-mean-square (rms) sound pressure. The instruments provide a measurement of sound pressure level in dB; the level emphasizes the fact that this is a measurement in relation to a given reference pressure. In air a reference pressure of 0.0002 microbar has been selected as a standard reference point. Sound pressure level (SPL) is defined by:

$$\text{SPL} = 20 \log_{10} \frac{P}{P_0} \text{ dB}$$

where P = measured rms sound pressure

P_0 = reference pressure

In Table I some typical sound pressures and sound pressure levels are shown.

Table I

Sound pressure (microbars)	Sound pressure level (dB re 0.0002 microbar)	Example
0.0002	0	Threshold of hearing
0.00063	10	
0.002	20	
0.0063	30	
0.02	40	
0.063	50	Residence Conventional speech
0.2	60	
0.63	70	
1.0	74	
2.0	80	
6.3	90	Subway Looms in textile mill Woodworking Hydraulic Press Jet plane
20	100	
63	110	
200	120	
2000	140	

Sound intensity units, which must also cover a wide range of values, can also be expressed by the decibel to an advantage. Intensity level (IL) is defined:

$$IL = 10 \log_{10} \frac{I}{I_0} \text{ dB}$$

where I = measured intensity
 I_0 = reference intensity

The reference commonly used is 10^{-16} watt/cm² which corresponds to 0.0002 microbar for plane or spherical waves in air at standard temperature and pressure.

Sound power level (PWL) is defined by:

$$PWL = 10 \log_{10} \frac{W}{W_0} \text{ dB}$$

where W = power of the source
 W_0 = a reference power

The arbitrarily chosen reference power commonly used is 10^{-12} watt.

It is important to have an understanding of the relationships among power, intensity, and sound pressure level. The following example should be helpful.

A new machine is being purchased, and the supplier can furnish the information that the machine will produce 1.0 watt of acoustical power. What will the sound pressure level be 100 feet from this equipment if free-field conditions are assumed? Given the equation

$$W = I_{\text{avg}} 4 \pi r^2 = \frac{P_{\text{avg}}^2 4 \pi r^2}{\rho c}$$

therefore,

$$P_{\text{avg}} = \sqrt{\frac{W \rho c}{4 \pi r^2}}$$

where:

W = power = 1.0 watt = $10^7 \frac{\text{ergs}}{\text{sec}}$

ρ = density of air = $0.0012 \frac{\text{gm}}{\text{cm}^3}$

c = speed of sound in

= 1,128 ft/sec = 34,381 cm/sec

$$P_{\text{avg}} = \sqrt{\frac{10^7 \frac{\text{ergs}}{\text{sec}} \times 0.0012 \frac{\text{gm}}{\text{cm}^3} \times 34,381 \frac{\text{cm}}{\text{sec}}}{4\pi (100 \text{ ft} \times 30.48 \frac{\text{cm}}{\text{ft}})^2}}$$

= 1.87 microbar

The sound pressure level can be computed as follows:

$$SPL = 20 \log_{10} \frac{1.87}{0.0002} \text{ microbar}$$

= 20×3.97

= 79.4 dB re 0.0002 microbar

Addition and Subtraction of Decibels

In sound survey work it is frequently necessary to combine sound pressure level readings. An example would be to evaluate the effect of adding a machine in a room where the noise level is already considered borderline. Since the decibel scale is logarithmic, decibel values cannot be added directly. The correct procedure is to convert the decibels to intensity ratios, add the intensity ratios, and reconvert this sum into decibels. Combining sound pressure levels can be done by using the following formula:

$$SPL_1 + SPL_2 + \dots + n = 10 \log_{10} \left[(10)^{\frac{SPL_1}{10}} + (10)^{\frac{SPL_2}{10}} + \dots + (10)^{\frac{SPL_n}{10}} \right]$$

Example:

Given:

$SPL_1 = 75 \text{ dB}$, $SPL_2 = 74 \text{ dB}$

Then:

$$\begin{aligned} SPL_1 + SPL_2 &= 10 \log_{10} (10^{7.5} + 10^{7.4}) \\ &= 10 \log_{10} (10^{0.5} \times 10^7 + 10^{0.4} \times 10^7) \\ &= 10 \log_{10} [(10^{0.5} + 10^{0.4})(10^7)] \\ &= 10 \log_{10} ((3.16 + 2.50)(10^7)) \\ &= 75 + 7.0 = 77.5 \text{ dB} \end{aligned}$$

Although it is possible to calculate the combined sound pressure level, as was done above, it is much easier to use a graph or a table such as Table II.

Table II

Difference between levels in dB	No. of dB to be added to higher level
0	3.0
1	2.6
2	2.1
3	1.8
4	1.5
5	1.2
6	1.0
7	0.8
8	0.6
10	0.4
12	0.3
14	0.2
16	0.1

In combining more than two sound pressure levels by this procedure, the two highest should be combined first. The total thus obtained is next combined with the highest remaining level, and this procedure is continued until all levels are combined.

In some cases, when measurements are made to determine the amount of noise generated by a particular source, it may be necessary to make corrections for background noise. If there is any evidence that the background noise is contributing to the noise being measured, a background measurement should be made with the noise source turned off. It is possible to make a rough correction for this background by applying the factors given in Table III.

Table III

Difference between Total Noise Level and Background level (dB)	No. of dB to be Subtracted from Total Noise Level to Find Noise Level Due to Source
10	0.5
9	0.6
8	0.7
7	1.0
6	1.2
5	1.6
4	2.2
3	3.0
2	4.3
1	6.9

Frequency Distribution of Sound Pressure

In conducting noise studies it is often necessary to determine the distribution of sound pressure with frequency because hearing loss, annoyance, speech interference, sound absorption, etc., all vary with frequency. This can be done by measuring the sound pressure in frequency bands of various widths. Those most commonly used are the octave, half-octave, and third-octave bands. An octave band is a frequency interval in which the upper frequency is twice the lower frequency, such as 150 to 300 cycles per second or 1200 to 2400 cycles per second.

Figure 2 illustrates data obtained from an octave band analysis of two different wide-band noises having the same total sound pressure level (98 dB). The energy contained in one sound appears to be uniformly distributed across the eight octave bands. The other noise shows the acoustical energy concentrated largely within one or two octave bands. Information about the spectra of the sound is helpful in evaluating the effects sound may have on individuals so exposed.

OCTAVE BAND ANALYSIS

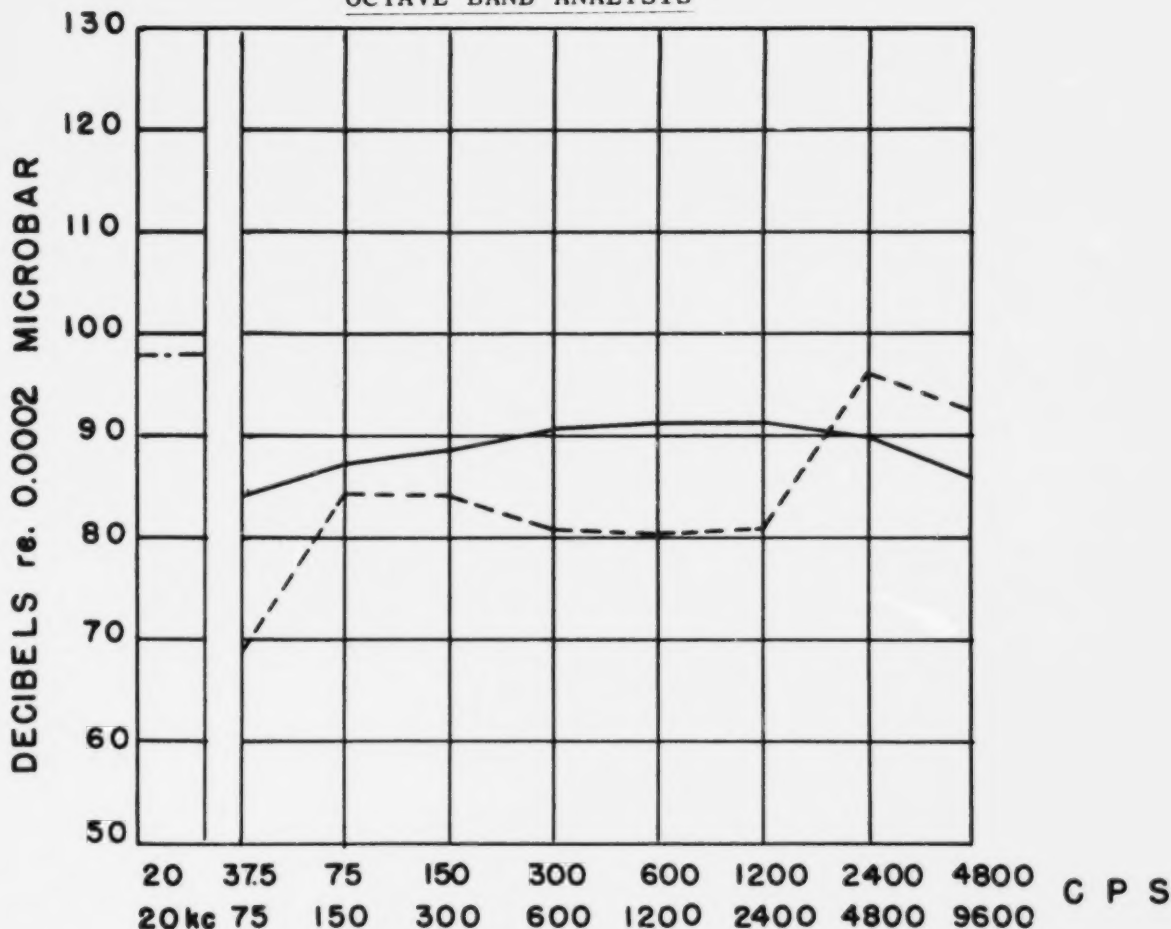


Figure 2. Spectral differences between two sounds having the same overall sound pressure levels.

Subjective Measurements of the Effects of Sound

In evaluating certain noise problems it may be helpful to determine what the subjective response to the noise would be rather than to rely on physical measurements alone. It is known that sounds of equal pressure may not be rated by listeners as being equally loud or annoying. A number of scales have been developed, by subjective experiments, for rating the loudness or annoyance of sounds.

In one investigation, the rating of loudness of sounds was made by determining the sound pressure levels of

pure tones of various frequencies that were judged by the observer to be as loud as a 1000-cps tone of a given sound pressure level. The sound pressure level in dB, re 0.0002 microbar, for a 100 cps pure tone, or any pure tone that is judged equally loud, is defined as the loudness level in phons. The result of this investigation are given in Figure 3, which shows contours of equal loudness.

The contours in Figure 3 serve well for comparing pure tones, but with industrial noises, where the noise is generally broad-band, another system has been devised using octave bands of noise. In this system the sone has been used as a

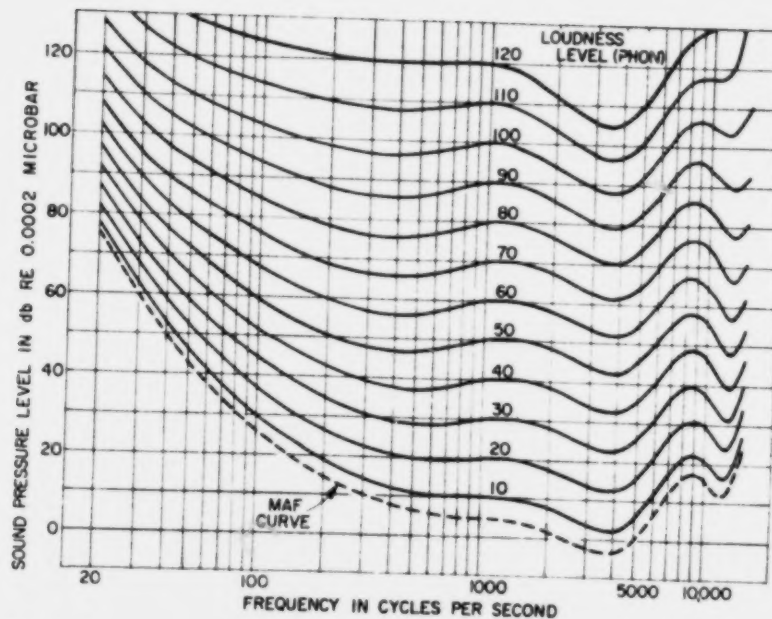


Figure 3. - Free-field equal-loudness contours for pure tones (observer facing source), determined by Robinson and Dodson at the National Physical Laboratory, Teddington, England.

Reproduced by courtesy of General Radio Company.

subjective index of loudness. One sone is defined as a 1000 cps tone of 40 dB re 0.0002 microbar, and any sound that would be judged twice as loud is two sones. By means of this method of comparison, an arithmetic scale of loudness was devised.

Procedure for the Calculation of Loudness

The procedure for calculating loudness involves the use of the formula below and the graph presented in Figure 4. The graph provides a means for converting each band level to a loudness index, and the formula provides a rule for combining the loudness indices in order to compute the total loudness.

The procedure is as follows:

1. Enter the geometric mean frequency of each band on the abscissa of Figure 4. Then from the band level (ordinate of Figure 4) determine the loudness index of each band.
2. Find the total loudness (S_t) by means of the formula:

$$S_t = S_m + F (\sum S - S_m)$$

Where:

S_m = largest loudness indices
 $\sum S$ = sum of the loudness indices of all bands
 F = factor which depends on band width

Band width	F
Third-octave	0.15
Half-octave	0.2
Octave	0.3

3. The total loudness may be converted into calculated loudness level (P) by means of the formula:

$$St = 2^{(P-40)/10}$$

$$\text{or } P = 40 + 10 \log_2 St$$

A nomogram giving this relation is included on the right side of Figure 4.

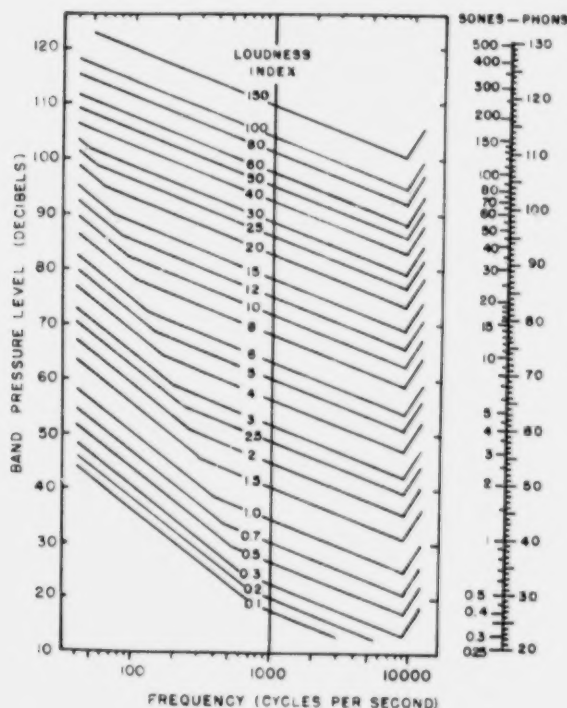


Figure 4. Contours of Equal Loudness Index (Stevens, S.S.)

Reproduced by courtesy of The Journal of Acoustical Society of America.

This procedure is based upon: Stevens, S.S., Procedure for Calculating Loudness: Mark VI, Journal of the Acoustical Society of America, Vol. 33, November 1961, pp 1577-1585.

Loudness alone may not determine the annoyance of a particular sound. Therefore, a subjective scale to measure annoyance has been devised as a result of studies in which the experimental subjects were asked to evaluate noise for annoyance rather than loudness. The unit of measurement in this arithmetic scale is the perceived noise level (PNdB). One PNdB is equivalent to a

1000 cps tone, 40 dB, re 0.0002 microbar; any sound judged twice as annoying is given a value of 2 PNdB.

Procedure for Calculating Perceived Noise Level in PNdB

The procedure for calculating perceived noise level in PNdB for sound pressure levels in octave bands of frequency is as follows:

Step 1: Convert the sound pressure levels (SPL) in each octave band to "noisiness" in noys by means of the appropriate column in Table IV.

Table IV*

PERCEIVED NOISE LEVELS (NOYS) - COMMERCIAL OCTAVE BAND FILTERS

FREQUENCY BAND LIMITS IN CYCLES PER SECOND

	37.5	75	150	300	600	1200	2400	4800
	75	150	300	600	1200	2400	4800	9600

	37.5	75	150	300	600	1200	2400	4800
	75	150	300	600	1200	2400	4800	9600

BAND CENTER FREQUENCY IN CYCLES PER SECOND

SPL	53	106	212	425	850	1700	3400	6800
10								
11	Bolt Beranek & Newmann, Inc.							
12	7 November 1962							
13	NASA-FAA NaSr 58						0.1	
14							0.1	
15							0.2	
16							0.2	
17						0.1	0.3	
18						0.1	0.3	
19						0.2	0.4	
20						0.2	0.4	
21						0.3	0.5	
22						0.3	0.6	0.1
23						0.4	0.6	0.2
24						0.4	0.7	0.2
25				0.1	0.1	0.5	0.7	0.3
26				0.2	0.2	0.6	0.8	0.3
27				0.2	0.2	0.6	0.9	0.4
28				0.3	0.3	0.7	0.9	0.5
29				0.3	0.3	0.7	1.0	0.6
30			0.1	0.4	0.4	0.8	1.1	0.6
31			0.1	0.4	0.4	0.9	1.2	0.7
32			0.2	0.5	0.5	0.9	1.2	0.8
33			0.2	0.6	0.6	1.0	1.3	0.9
34			0.3	0.6	0.6	1.1	1.4	1.0
35			0.3	0.7	0.7	1.2	1.5	1.1
36			0.4	0.7	0.7	1.3	1.6	1.2
37			0.4	0.8	0.8	1.3	1.8	1.4
38		0.1	0.5	0.9	0.9	1.4	1.9	1.5
39		0.2	0.6	0.9	0.9	1.5	2.0	1.6
40		0.2	0.6	1.0	1.0	1.6	2.2	1.8
41		0.3	0.7	1.1	1.1	1.7	2.4	1.9
42		0.3	0.7	1.2	1.2	1.8	2.6	2.0
43		0.4	0.8	1.2	1.2	2.0	2.8	2.2
44		0.5	0.9	1.3	1.3	2.1	3.0	2.4
45		0.5	0.9	1.4	1.4	2.3	3.2	2.6

SPL	53	106	212	425	850	1700	3400	6800
46		0.6	1.0	1.5	1.5	2.4	3.4	2.8
47		0.6	1.1	1.6	1.6	2.6	3.6	3.0
48		0.7	1.2	1.7	1.7	2.8	3.9	3.2
49		0.7	1.3	1.9	1.9	3.0	4.1	3.4
50		0.8	1.4	2.0	2.0	3.2	4.4	3.6
51		0.9	1.5	2.1	2.1	3.5	4.7	3.9
52	0.1	1.0	1.6	2.3	2.3	3.7	5.0	4.1
53	0.2	1.0	1.7	2.4	2.4	4.0	5.3	4.4
54	0.2	1.1	1.9	2.6	2.6	4.3	5.7	4.7
55	0.3	1.2	2.0	2.8	2.8	4.6	6.1	5.0
56	0.4	1.3	2.2	3.0	3.0	5.0	6.5	5.3
57	0.4	1.4	2.4	3.2	3.2	5.3	7.0	5.7
58	0.5	2.6	1.5	3.5	3.5	5.7	7.5	6.1
59	0.6	1.7	2.8	3.7	3.7	6.1	8.0	6.5
60	0.7	1.8	3.0	4.0	4.0	6.5	8.7	7.0
61	0.8	2.0	3.2	4.3	4.3	7.0	9.3	7.5
62	0.9	2.2	3.5	4.6	4.6	7.5	10.	8.0
63	1.0	2.4	3.7	5.0	5.0	8.0	11.	8.7
64	1.1	2.6	4.0	5.3	5.3	8.7	11.	9.3
65	1.2	2.8	4.3	5.7	5.7	9.3	12.	10.
66	1.4	3.0	4.6	6.1	6.1	10.	13.	11.
67	1.6	3.3	5.0	6.5	6.5	11.	14.	11.
68	1.8	3.6	5.4	7.0	7.0	11.	15.	12.
69	2.0	3.9	5.9	7.5	7.5	12.	16.	13.
70	2.2	4.2	6.4	8.0	8.0	13.	17.	14.
71	2.3	4.6	6.9	8.7	8.7	14.	19.	15.
72	2.5	5.0	7.5	9.3	9.3	15.	20.	16.
73	2.8	5.4	8.0	10.	10.	16.	21.	17.
74	3.0	5.9	8.7	11.	11.	17.	23.	19.
75	3.3	6.4	9.3	11.	11.	19.	24.	20.
76	3.7	6.9	10.	12.	12.	20.	26.	21.
77	4.1	7.5	11.	13.	13.	21.	28.	23.
78	4.5	8.2	11.	14.	14.	23.	30.	24.
79	5.0	9.1	12.	15.	15.	24.	32.	26.
80	5.5	10.	13.	16.	16.	26.	35.	28.

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Table IV (continued)

	37.5	75	150	300	600	1200	2400	4800
	75	150	300	600	1200	2400	4800	9600

BAND CENTER FREQUENCY IN CYCLES PER SECOND

SPL	53	106	212	425	850	1700	3400	6800
81	6.1	11.	14.	17.	17.	28.	37.	30.
82	6.8	11.	15.	19.	19.	30.	40.	32.
83	7.5	12.	16.	20.	20.	32.	42.	35.
84	8.3	13.	17.	21.	21.	35.	45.	37.
85	9.1	14.	19.	23.	23.	37.	47.	40.
86	10.	15.	20.	24.	24.	40.	50.	42.
87	12.	16.	21.	26.	26.	42.	55.	45.
88	13.	17.	23.	28.	28.	45.	60.	47.
89	13.	19.	24.	30.	30.	47.	63.	50.
90	14.	20.	26.	32.	32.	50.	67.	55.
91	15.	21.	28.	35.	35.	55.	71.	60.
92	16.	23.	30.	37.	37.	60.	75.	63.
93	17.	24.	32.	40.	40.	63.	80.	67.
94	19.	26.	35.	42.	42.	67.	86.	71.
95	20.	28.	37.	45.	45.	71.	93.	75.
96	21.	30.	40.	47.	47.	75.	100.	80.
97	23.	32.	42.	50.	50.	80.	108.	86.
98	24.	35.	45.	55.	55.	86.	116.	93.
99	26.	37.	47.	60.	60.	93.	125.	100.
100	28.	40.	50.	64.	65.	100.	133.	108.
101	30.	42.	55.	69.	69.	108.	142.	116.
102	32.	45.	66.	74.	74.	116.	150.	125.
103	35.	47.	64.	80.	80.	125.	162.	133.
104	37.	50.	69.	85.	85.	133.	173.	142.
105	40.	55.	74.	89.	89.	142.	186.	150.
106	42.	60.	80.	94.	94.	150.	200.	162.
107	45.	64.	85.	100.	100.	162.	215.	173.
108	47.	69.	89.	108.	108.	173.	232.	186.
109	50.	74.	94.	116.	116.	186.	250.	200.
110	55.	80.	100.	125.	125.	200.		215.
111	60.	85.	108.	133.	133.	215.		232.
112	64.	89.	116.	142.	142.	232.		250.
113	69.	94.	125.	150.	150.	250.		
114	74.	100.	133.	162.	162.			
115	80.	108.	142.	173.	173.			
116	86.	116.	150.	186.	186.			
117	93.	125.	162.	200.	200.			
118	100.	133.	173.	215.	215.			
119	108.	142.	186.	232.	232.			
120	116.	150.	200.	250.	250.			
121	125.	162.	215.					
122	133.	173.	232.					
123	142.	186.	250.					
124	150.	200.						
125	162.	215.						
126	173.	232.						
127	186.	250.						
128	200.							
129	215.							
130	232.							
131	250.							

Step 2: Add the eight values of noys to obtain ΣN .

Step 3: Subtract the maximum of the eight noys values (N_m) from the total (ΣN) to obtain ($\Sigma N - N_m$).

Step 4: Multiply ($\Sigma N - N_m$) by 0.3.

Step 5: Add the maximum noy value N_m to obtain N_T which is equal to

$$0.3(\Sigma N - N_m) + N_m$$

Step 6: Convert N_T to perceived noise level in PNdB by means of the formula:

$$\text{PNdB} = 40 + 33.3 \log_{10} N_T$$

Example: To compute the perceived noise level in PNdB for the following spectrum:

Octave band cps	Sound pressure level dB	Noys
37.5 - 75	95	20
75 - 150	98	35
150 - 300	102	60
300 - 600	105	89
600 - 1200	103	80
1200 - 2400	100	100
2400 - 4800	95	93
4800 - 9600	92	63
		540 (ΣN)
		- 100 (N_m)
		440
		x 0.3
		132.0
		+ 100 (N_m)
		232 (N_T)

$$\text{PNdB} = 40 + 33.3 \log_{10} N_T$$

$$\text{PNdB} = 40 + (33.3)(2.36)$$

$$\text{PNdB} = 119$$

PHYSIOLOGY OF HEARING

Major interest in this section will be given to the structure and function of the ear as related to the hearing process and its impairment due to excessive noise exposure. The brain mechanisms

underlying the hearing process will be largely ignored since noise-induced hearing loss seems to be primarily a peripheral as opposed to a central-type of disorder.

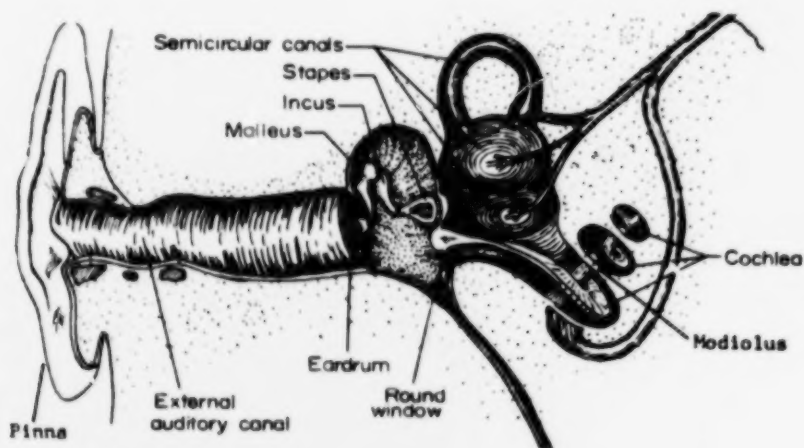


Figure 1.-Drawing of human ear showing three subdivisions in cross section.

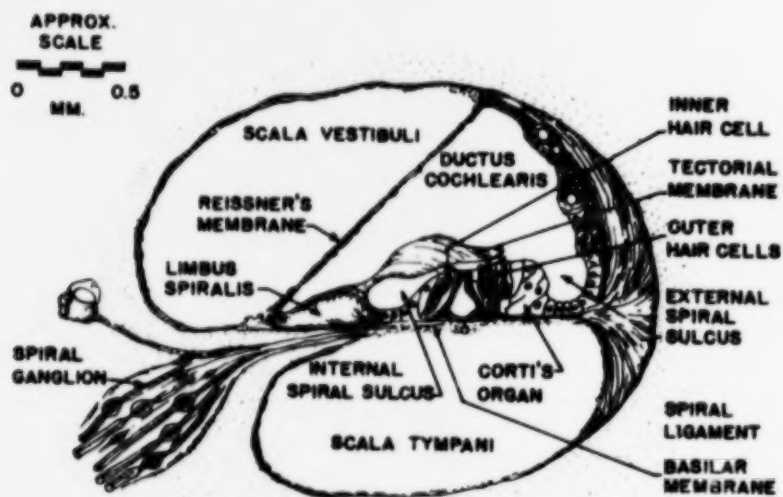


Figure 2.-Enlarged cross-section drawing of the cochlea.

Prepared by: Alexander Cohen, Ph.D.

Ear Anatomy and Physiology

Anatomically, the ear can be divided into three subdivisions called the external, middle and inner ears (see Figure 1). The external and middle ear functions are principally to collect and transmit sound stimuli to the inner ear where the sensory receptors for sound sensation are located. The pinna of the external ear funnels sound inward through the external ear canal to the tympanic membrane or eardrum. The incoming sound waves strike the eardrum and set it into vibration. Behind the eardrum is the middle ear, an air-filled cavity containing three small bones or ossicles referred to as the malleus, incus and stapes. The handle of the malleus is attached to the eardrum and articulates with the incus which, in turn, is joined to the stapes. The footplate of the stapes fits snugly in the oval window which is one of the two covered openings between the middle and inner ears. The other opening lies just below the oval window and is called the round window. Functionally, the three ossicles form a chain which carry the sound-produced vibrations of the eardrum through the middle ear to the inner ear.

Also located in the middle ear are the intra-aural ear muscles consisting of the tensor tympani and the stapedius. The tensor tympani is attached to the malleus and, when contracted, places the eardrum under greater tension. The stapedius muscle is fastened to the stapes and upon contraction pulls this bone in a downward and outward direction therein affecting the movement of the stapes footplate in the oval window. The contractile state of these muscles can be produced by the onset of intense sound and, in effect, reduces the amount of sound energy that is conducted by the ossicular chain to the inner ear. This action is considered protective in nature since it minimizes the potentially damaging effects of high intensity sounds on the hearing receptors in the inner ear.

Another middle ear feature is the Eustachian tube, a passageway leading from the middle ear cavity to the back of the nose and throat. The purpose of the tube is to equalize air pressure on both sides of the eardrum. Equalization in pressure is necessary to make the eardrum more capable of responding to and transmitting the sounds impinging upon it.

Just behind the oval and round windows is the inner ear which consists of three sections known as the vestibule, semicircular canals, and cochlea. Of these, the cochlea is the most important for hearing. The human cochlea is essentially a triple canal coiled up spirally around a bony axis, the modiolus, which is channeled to form the pathway for the auditory branch of the VIIIth cranial nerve. The larger turns of the spiral are at the base of the cochlea, the smaller turns are at the apex. The three canals comprising the cochlea are formed by two partitions (see Figure 2). One partition is composed of a ledge of bone, the spiral lamina, which winds around the modiolus like the thread of a screw and the basilar membrane which extends from the projecting tip of the spiral lamina to the outer wall of the cochlea. The second partition is formed by Reissner's membrane which stretches from the upper surface of the spiral lamina to a point on the outer wall of the cochlea, a short distance above the attachment of the basilar membrane. The canal, which lies below the basilar membrane, is called the tympanic canal (scala tympani); the canal enclosed between the basilar membrane and Reissner's membrane is called the cochlear duct (ductus cochlearis), and the canal lying above Reissner's membrane is referred to as the vestibular canal (scala vestibuli). The vestibular and tympanic canals contain perilymph fluid and communicate with one another through a tiny opening at the apex of the cochlea. The base of the vestibular canal is sealed by the oval window into which the footplate of the stapes is lodged.

The lower termination of the tympanic canal is sealed by the membrane-covered round window. The cochlear duct contains endolymph fluid and also the tectorial membrane which is attached at one end to the spiral lamina with the other end floating freely in the endolymph just above the basilar membrane.

The basilar membrane is narrowest at the base of the cochlea (i.e., near the oval window) and becomes progressively wider as it extends towards the apex. This is in contradistinction to the dimensions of the total cochlear structure which becomes smaller as the apex is approached. Distributed in four rows (one inner row, three outer rows) along the entire length of the basilar membrane are hair cells which project upward toward the underside of the tectorial membrane. These hair cells are the sensory receptors for hearing which together with supporting cells constitute the Organ of Corti, the auditory sense organ. The hair cells are innervated by nerve fibers which pass through small openings in the spiral lamina and enter the modiolus of the cochlea where their cell bodies are grouped to form the spiral ganglion. Axons from this ganglion collect at the base of the cochlea and pass out from the bottom of the coil as the auditory branch of the VIIIth cranial nerve. These axons end upon nerves in the medulla, which, in turn, pass axons to different and higher nerve centers in the thalamus and cerebellum. Axons from these centers finally lead to the temporal lobe of the cerebral cortex.

Although knowledge is still lacking, cochlear function underlying the hearing process has become clearer in recent years. As a physical system the cochlea has been described as an enclosed column of fluid bounded at one end by the stapes footplate in the round window and at the other end by the membrane covering the round window. Since fluid is incompressible, the vibrations transmitted by the stapes footplate, similar to a plunger action, cause mass move-

ments of fluids in the cochlear canals. In this process every inward movement of the stapes footplate causes the round window to bulge outward, and every stapes outward movement causes the round window to move inward. The fluid movements in the cochlear canals cause structural displacements along the basilar membrane which take the form of a traveling wave whose crest reaches a peak at different points along the membrane depending upon the frequency of sound stimulation. Generally, the locus of the crest or peak displacement for high frequency sounds is in the basal section of the basilar membrane, the peaks for lower frequencies becoming progressively shifted toward the apex of the basilar membrane.

As a result of the wavelike motions of the basilar membrane, a shearing action develops between the basilar membrane and the tectorial membrane leading to bending and squeezing of the hair cells found on the upper surface of the basilar membrane. This hair cell deformation causes electrical and/or chemical changes which are believed to trigger nerve impulses in the nerve fibers associated with the hair cells. The pattern of neural impulses arising within the cochlea provides the basis for auditory sensation and is transmitted to the cerebral cortex for interpretation.

Hearing Loss from Noise Exposure

Deafness may be classified into three basic types, namely, conductive, perceptive (neural) and functional. Conductive hearing loss is caused by a disorder in the external and/or middle ear which prevents the normal amount of sound energy from reaching the inner ear. This pathology may vary from excessive wax being formed in the external ear canal to a bony sclerosis or hardening of tissue around the footplate of the stapes in the oval window (called otosclerosis). Most conductive-type impairments are amenable to treatment and can be corrected. Perceptive deaf-

ness refers to disorders in the inner ear and/or along the VIIIth cranial nerve. Such pathology may range from disturbance in the cochlear fluids to degeneration of the hair cell receptors and nerve supply. These types of loss are not capable of being restored through surgical or other medical means.

Functional deafness is applied to a hearing loss that has no organic basis. In other words, the individual does not fully utilize his hearing capacity despite the fact that there is no actual damage to his hearing mechanism.

Hearing loss from noise exposure can be either conductive or neural in nature. Occasionally, it may even be a combination of the two. Noise-induced hearing loss of a conductive type, termed acoustic or blast trauma, can result from an explosion which may rupture the eardrum. The inner ear is infrequently damaged in such instances, but the ossicular chain may be dislodged. The perceptive type of noise-induced hearing loss results from prolonged exposure to excessive amounts of noise such as may be found in industry. The eardrum or ossicular chain is rarely affected in these cases, the site of this disorder is in the cochlea. Initial exposure to excessive industrial-type noise produces a temporary loss in hearing which is recovered after a short time away from noise. With repeated or prolonged exposure for months or years, the likelihood of the ear recovering all of its temporary noise-induced loss is diminished. The residual or non-recovered part of the loss constitutes a permanent hearing impairment due to noise.

The mechanism responsible for deafness from noise exposure remains to be more fully determined. One author⁽⁴⁾ suggests that since the Organ of Corti has no direct blood supply, its capacity for rapid exchange of cell nutrients and waste products is quite limited. Thus, even short periods of acoustic over-stimulation can cause cellular depletion with consequent decreased cell sensi-

tivity. It is this effect that seems manifest in temporary hearing loss or temporary threshold shift (TTS). While in this lowered physiological state, continued acoustic over-stimulation will cause still more cellular depletion to a point where complete recovery cannot take place. The result is reflected as a permanent loss in hearing sensitivity.

Histological studies (summarized in Ref. 4) have shown that the regions of cellular injury due to excessive noise exposure are localized on the basilar membrane, the location and width of such regions depending on the characteristics of the over-stimulating sound. Generally speaking, however, the cellular areas of the membrane mediating high frequency sensitivity (more basal in direction) show more vulnerability to noise-induced damage than do those receptor regions underlying low frequency sensitivity (more apical in direction). There are several reasons for this differential finding. Among these are: (1) the high frequency membrane regions give higher amplitudes and more sharply concentrated patterns of response to incoming stimulation; (2) the middle ear reflex shows less attenuation (hence, less protection) for high frequency as compared with low frequency sounds; and (3) the resonant frequency of the external ear canal will give added amplification to high frequency relative to low frequency sounds.

Regardless of the site of the basilar membrane, the process of noise-induced damage is essentially the same. Damage occurs first to the outer hair cells and their supporting structures. The inner hair cells seem generally to be the last sensory structure damaged. The final irreversible stage of the process is the complete dissolution of the Organ of Corti, leaving a denuded section of the basilar membrane. Subsequently, these damaged sections are replaced by a layer of epithelial cells.

As already mentioned, perceptive-type deafness is not curable. Noise-induced

losses of the perceptive-type can be prevented, however, and all feasible efforts must be taken to insure such prevention.

Audiometry

Hearing losses can be measured by a pure-tone audiometer which describes threshold intensity levels for hearing different frequency sounds relative to intensity values representing the average hearing of a normal listener popu-

lation. (Note: these reference settings are not to be confused with the 0.0002 microbar reference for sound pressure level measurements. Actually, the reference values for normal hearing on the audiometer are different for different test frequencies⁰. Pure-tone air conduction audiometry is most commonly used in hearing testing although bone conduction and other more elaborate tests (e.g., noise-masked thresholds or pure-tone discrimination) are also used for purposes of diagnosing a given hearing disorder.

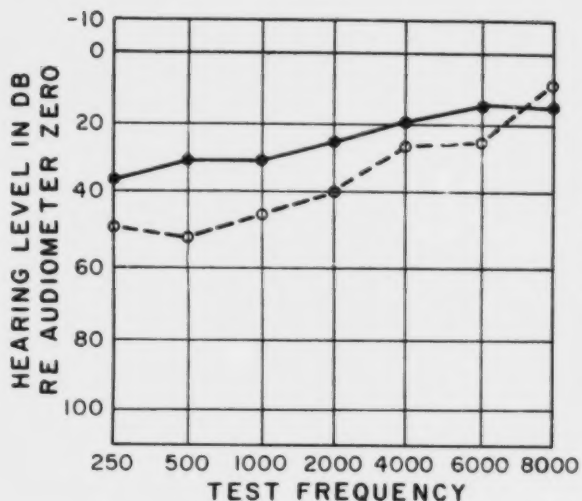


Figure 3. - Audiogram showing conductive type hearing impairment.

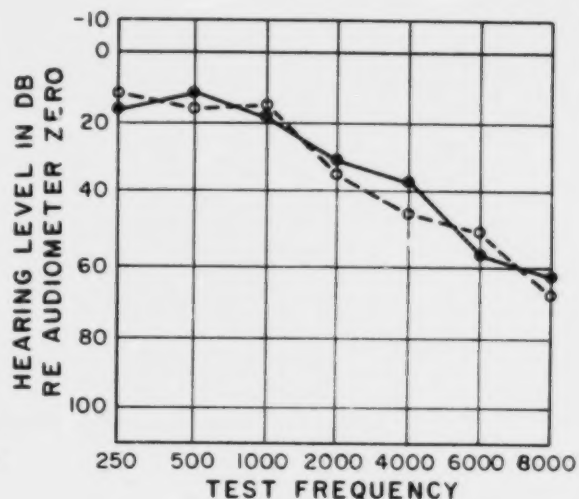


Figure 4. - Audiogram showing perceptive type hearing impairment.

Figures 3 and 4 show typical audiograms for ears with conductive and perceptive hearing losses, respectively. Note that in the conductive case (Figure 3) the losses for low frequency sounds are greater than those for the higher frequencies. In contrast the perceptive hearing disorder (Figure 4) shows relatively greater losses at the higher frequencies. Figure 5 describes the

development of permanent noise-induced hearing loss as a function of exposure time to excessive industrial noise. Early in the development, the losses are most prominent for frequencies of 3000 to 6000 cps and show a peak at 4000 cps. With continued exposure significant losses appear at other neighboring frequencies as well as increases still further in the 3000-6000 cps range.

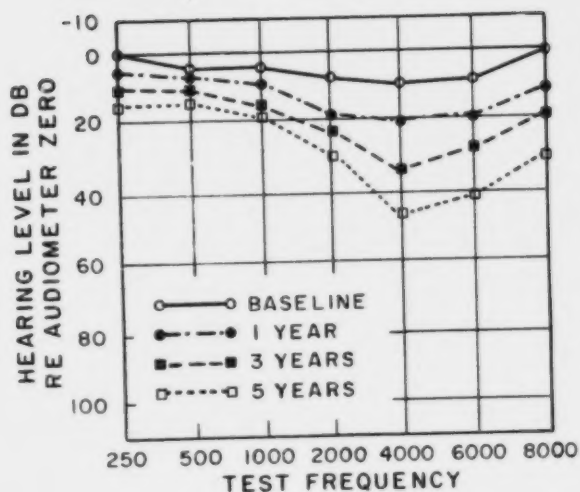


Figure 5. - Hearing loss from noise as a function of exposure time.

Deafness due to aging (presbycusis) also shows losses in the audiogram at those frequencies severely affected by noise exposure. This raises the problem of how much of a given hearing loss at a test frequency is due to noise and how much is due to age. Hearing data acquired from noise-free populations of listeners, classified by age, are presently being used to estimate the extent of hearing loss due to the age factor only. Such losses are deducted from audiometric measurement on noise-exposed individuals, leaving a value which is believed to more accurately reflect the extent of the noise-induced loss. In actuality, however, their procedure may give invalid results since age and susceptibility to noise-induced hearing loss may be subject to unique interactions.

References

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Introduction

By definition, noise is unwanted sound. Indeed, excessive noise can cause hearing loss and other undesired physiological changes, interference in speech communication, some loss in work efficiency, and, of course, annoyance. Although noise appears capable of producing such adverse effects, clarification is needed as to the health significance of these various alterations, the levels and types of noise conditions required to produce them, and the mechanisms underlying the specific

noise-induced effect noted. Information bearing on these issues will be included in this review which is largely intended to elucidate the physiological and psychological effects of noise having relevance to industrial as well as community noise problems.

Noise and Hearing Loss

Noise-induced hearing loss is believed to be a major health problem in industry and for this reason will be given prime emphasis in this review.

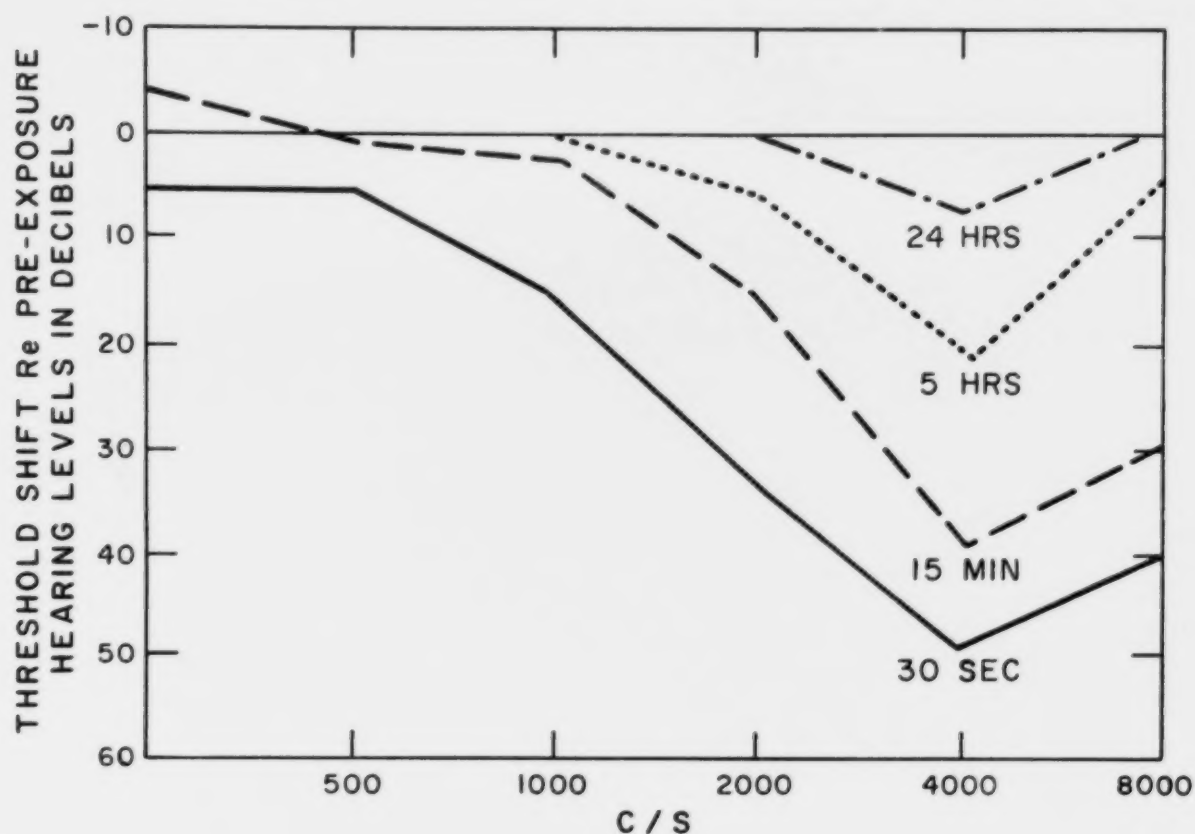


Figure 1. - Changes in hearing thresholds relative to pre-exposure values for different frequencies measured at various times after a twenty-minute exposure to 115 dB broad-band noise. (Unpublished data).

Prepared by: Alexander Cohen, Ph.D.

Exposing the ear to an intense noise will most probably cause hearing loss. This loss may be temporary, permanent, or a combination of the two. Temporary hearing loss, sometimes called temporary threshold shift or auditory fatigue, represents loss in hearing acuity that can occur after a few minutes exposure to an intense noise and is recoverable following a period of time away from the noise. Figure 1 shows hearing threshold levels, i.e., minimum audible sound levels, for different pure tone test frequencies measured at various times following a twenty-minute exposure to an intense broad-band noise. The horizontal line drawn through the '0' hearing level value on the vertical axis represents a listener's pre-exposure threshold level for hearing the different test frequencies. Differences between these hearing levels and

those plotted on the remaining curves indicate the extent of the listener's loss at specified times following the noise exposure. Note how the differences between the pre- and post-exposure hearing levels diminish with increasing time away from the noise, therein depicting the recovery of the ear from this noise exposure.

With daily continuous exposures for months or years to intense noise, there may be only partial recovery of the observed loss, the non-recoverable or residual loss being indicative of a permanent noise-induced hearing impairment. Figure 2 describes apparent permanent hearing losses for jute weavers as a function of their years of exposure to weaving room noise.⁽³⁷⁾ It is indicated that significant hearing losses occur first in the frequency range 3000

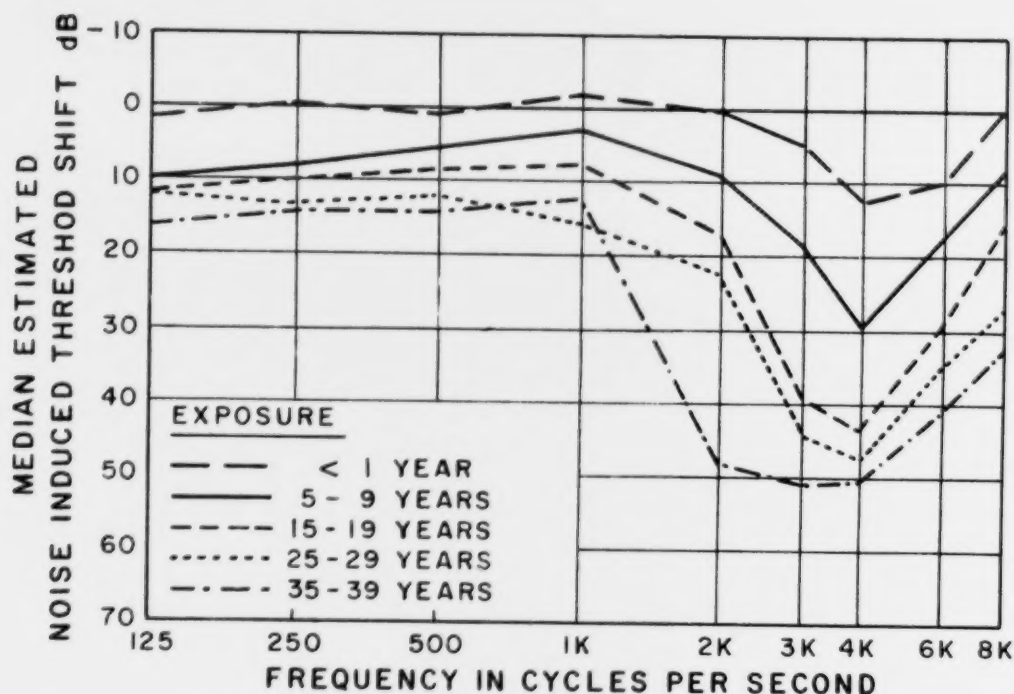


Figure 2. • Median noise-induced hearing changes for jute weavers as a function of years of exposure to weaving machinery noise. Data taken from Taylor, Pearson, Mair, and Burns.⁽³⁷⁾

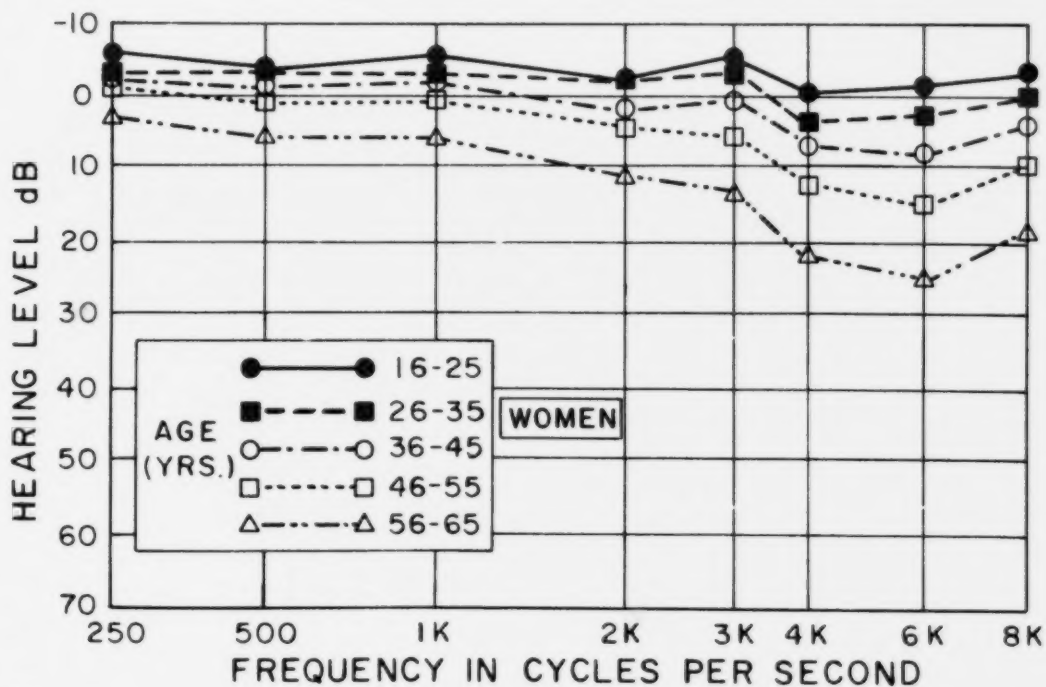
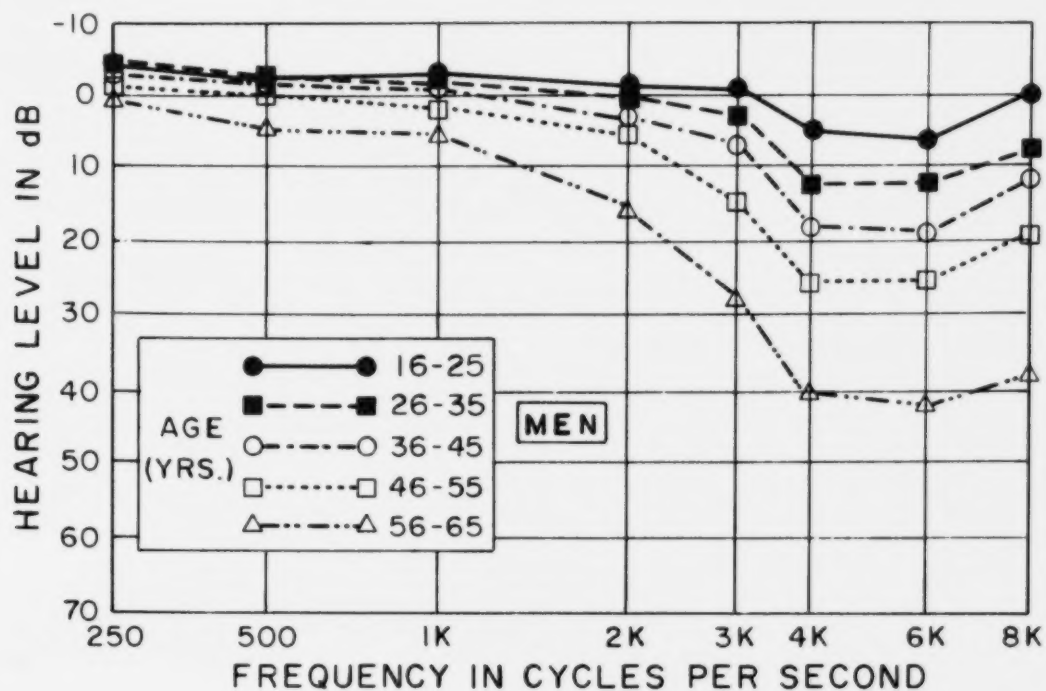


Figure 3. - Mean hearing levels as a function of age and sex for persons having minimal exposure to noise and no otological impairments. Data replotted from Riley et al.⁽²⁸⁾

to 6000 cycles per second (cps) on the audiogram, with 4000 cps showing the most sizeable impairment. Losses in this frequency range are not believed critical to speech reception so that the individual may be completely unaware of the signs of a noise-induced hearing loss, and with longer exposure time significant hearing loss that can affect speech perception also occurs at frequencies below 3000 cps. Workman's compensation laws for industrial hearing loss in several states presently regard only the hearing losses in the speech frequency range 500 to 2000 cps as being compensable.(3)

As already noted (see Section N-3), the evaluation of hearing loss due to noise is complicated by the fact that hearing acuity normally decreases with increasing age.(13,28) Further, the losses associated with age are quite similar to those caused by undue noise in that the hearing for high frequency sounds is most affected in both instances (compare Figures 2 and 3). Consequently, how much of a given worker's hearing loss is caused by occupational noise exposure? -- and how much is due to his age? Hearing data for different age and sex groups having had negligible noise exposure, such as shown in Figure 3, are subtracted from the total hearing loss values obtained for noise exposed persons in order to leave a "purer estimate" of the amount of noise-induced loss. The hearing loss data plotted in Figure 2 for the jute weavers have already been corrected for the age effects on hearing. This procedure for differentiating the two types of losses assumes that hearing changes due to noise and age are strictly independent. The validity of this assumption remains to be determined.

The factors believed to be critical in assessing the severity of noise exposure on hearing are the following:

1. The overall sound level of the noise.
2. The spectrum of the noise.
3. The total duration of noise exposure.

4. The frequency and time distribution of noise exposure.
5. The susceptibility of the exposed individual's ears to noise-induced hearing loss.

With reference to overall sound levels of noise and hearing loss (1 above), it is believed that exposing unprotected ears to noise in excess of 135 dB is hazardous and should be avoided.(2) At the other extreme, exposure to noise whose overall sound level falls below 78 dB(16,33) will not produce significant temporary hearing loss in unprotected ears and therefore is not assumed to cause any permanent hearing loss. Most industrial noise conditions fall between these two limits and require other information, such as the noise spectrum and the length of exposure, before a judgment can be made as to the potential harmfulness of the noise to hearing.

With reference to a noise spectra and hearing loss (2 above), it is believed that noises containing large concentrations of energy in the middle and high frequency regions (octave-bands 600-1200 cps and higher) are more damaging to hearing than those noises in which the energy is centered in the very low frequency regions (below 600 cps).(25,38) Thus, the octave-band spectrum for the annealing furnace noise in Figure 4, showing more noise energy in the higher frequencies, would have a greater potential for causing hearing loss than would the forging hammer noise which, although having the same overall level as the furnace noise, has most of its energy in the lower frequency regions. Fortunately, noise reduction treatment procedures are quite effective in suppressing the more damaging high frequency sound.(31,42) They are least effective in attenuating the less harmful low frequencies.

The shape of the noise spectra may also have a bearing on hearing loss. Specifically, those spectra with sharp peaks, that is, intense energy focussed in a

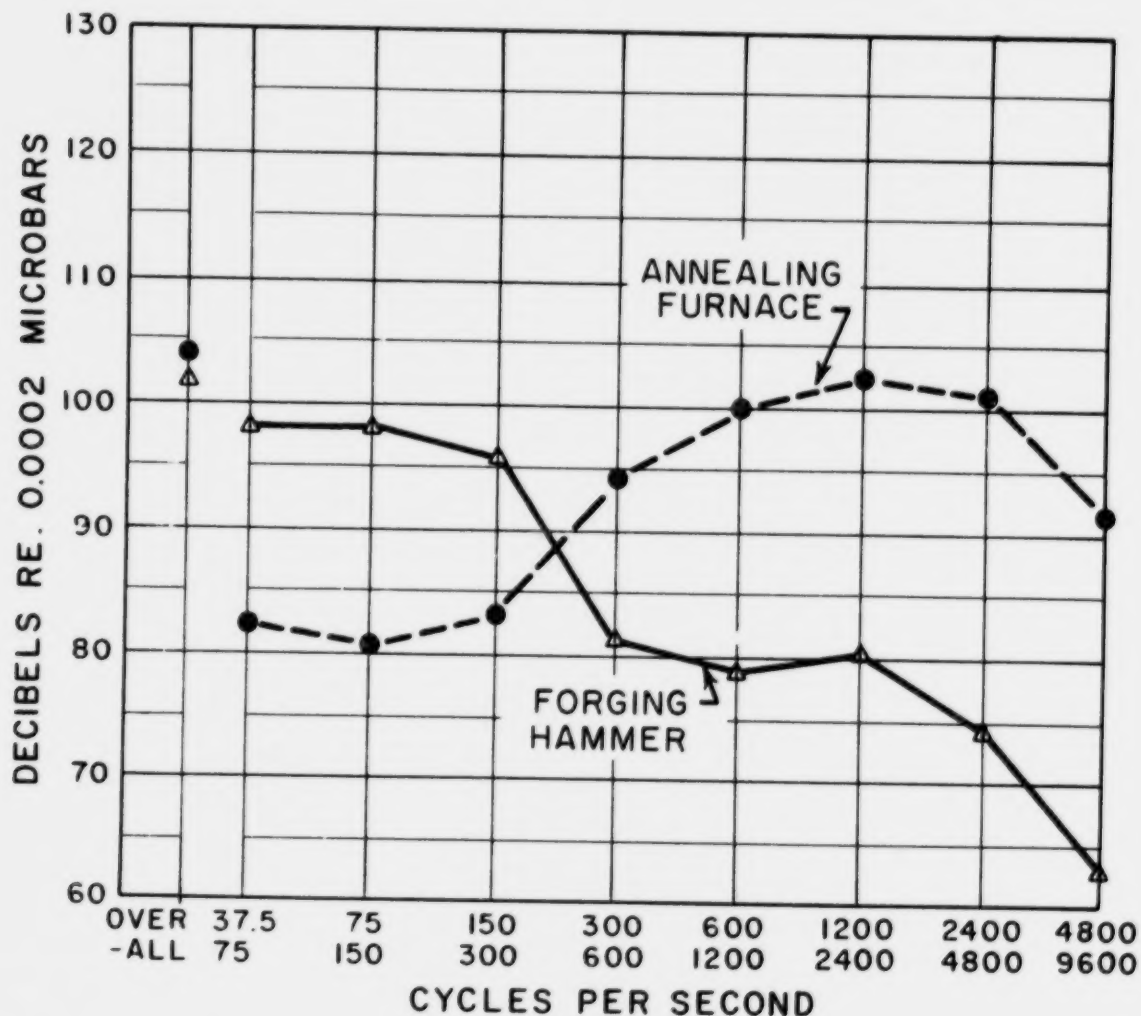


Figure 4. - Overall and octave-band SPL values in dB for noise from an annealing furnace and from forging hammer. Data taken from Noise Manual - American Industrial Hygiene Association, Detroit, Michigan, April 1958, pg. 1-5.

narrow-frequency band (less than an octave in width) and/or at a single frequency, are believed to pose an increased hazard to hearing when compared with spectral conditions revealing a more continuous distribution of energy across a broad range of frequencies.(11)

Total duration of noise exposure (3 above), as related to hearing loss is of increasing concern. When the total exposure time to an excessive

noise increases so does the incidence and magnitude of permanent noise-induced hearing impairment. Recently, however, it was shown that the amount of permanent hearing loss at 4000 cps stemming from daily exposures of five to eight hours to noise reached a maximum at about twelve years of exposure.(17) Further losses at this frequency with continuing exposure appeared to be due to the aging process (presbycusis). This finding is believed particularly significant since the

greatest loss from industrial noise exposure usually occurs at 4000 cps. An incidental finding here was that the maximum permanent hearing loss at 4000 cps after ten years exposure closely corresponded to the temporary hearing loss noted at the same frequency for a new employee group after their first days exposure to the same noise conditions. This would suggest that temporary hearing loss might be correlated with permanent hearing loss and therein serve as an indicator of the susceptibility of a given ear to noise-induced hearing loss. The relationship between permanent and temporary hearing loss is still not firmly established, however, and to some experts it appears untenable.⁽³²⁾ The frequency and time distribution of noise exposure (4 above), and possibility of resulting hearing loss take account of the fact that industrial noise exposure for a given worker is not always continuous or constant in nature. Most typically the worker is intermittently exposed to noise conditions which are fluctuating in level as well as spectra. Under these conditions, it is difficult to quantify accurately the amount of noise impinging upon the worker so that some judgment can be made about the harmfulness of the exposure. Much like a radiation badge, noise dosimeters are now being developed which can be worn by an individual for purposes of totalizing the amount of sound energy to which he is exposed. Through read-out devices and some routine computation, the dosimeter provides decibel reading for sound energy averaged over any desired time period. These more definitive estimates of intermittent noise exposure, when correlated with hearing loss, will provide a basis for establishing more realistic noise limits for such exposure situations. At the present time there is little agreement as to the establishment of noise exposure limits for intermittent exposure conditions.⁽¹²⁾ Most experts do agree, however, that less hearing loss will occur from an intermittent exposure to noise than from a continuous one of

the same total energy.^(16,38) This would suggest that rotating a worker in and out of a continuous type noise situation will provide some protection to his hearing.

Individual susceptibility (5 above), to both temporary as well as noise-induced hearing loss may vary greatly from one person to another. For this reason, some effort has been directed toward developing a technique that will identify the noise-susceptible or weak ears. Several investigators have considered the use of temporary threshold losses following a standardized noise exposure test as a susceptibility indicator.^(16,39) Those persons showing the greatest temporary losses from the exposure would be considered as most susceptible to permanent hearing losses and consequently would be placed in non-noisy work areas or otherwise protected. This procedure is not fully accepted at this time because of insufficient data concerning the relationship between temporary and permanent hearing loss. Measures of temporary hearing loss are being used, however, to check whether workers in noisy areas are using the ear protection issued to them. Individual workers may be selected for spot audiometric tests. If excessive threshold losses are noted relative to some previously obtained hearing values, it is considered as evidence that ear protection is not being used.

At present, attempts are being made to establish valid and acceptable noise tolerance criteria for preventing hearing damage. The need for such criteria in industry cannot be over-emphasized. They could serve as guidelines for (1) determining the noise reduction needed to create an acoustically safe work environment, (2) the establishment of hearing conservation programs which would include monitoring audiometry so as to identify early those ears that are unusually susceptible to noise-induced loss, and (3) fair rulings in court cases involving compensation

claims for noise-induced hearing loss. Many proposals for damage risk criteria to noise exposure have been made which are intended to minimize the risk of noise-induced hearing loss in a vast majority of the exposed worker population for their working lifetime. (2,16, 18, 21, 24, 27) Several of those criteria governing five 8-hour continuous exposure to noise on a daily basis are shown in Figure 5. Each of the plotted curves represents maximum octave band limits for noise exposure and, if exceeded, would prompt recommendations for ear protection or other means of noise control. Although not too different, a given noise condition could be considered safe in applying one crite-

rion and unsafe in applying another. Which of these various criteria has most merit in reducing the risk of noise-induced hearing loss, while not, of course, requiring needless amounts of noise control, remains to be completely determined. Answers to this question are sought in studies correlating hearing loss with long term exposure to noise conditions defined as safe or unsafe by the various criteria. The U.S. Public Health Service⁽⁴⁰⁾ conducted such a study in prison industries where groups of inmates experiencing known occupational noise conditions were given pre-employment and follow-up hearing tests at regular intervals to determine apparent hearing changes with duration

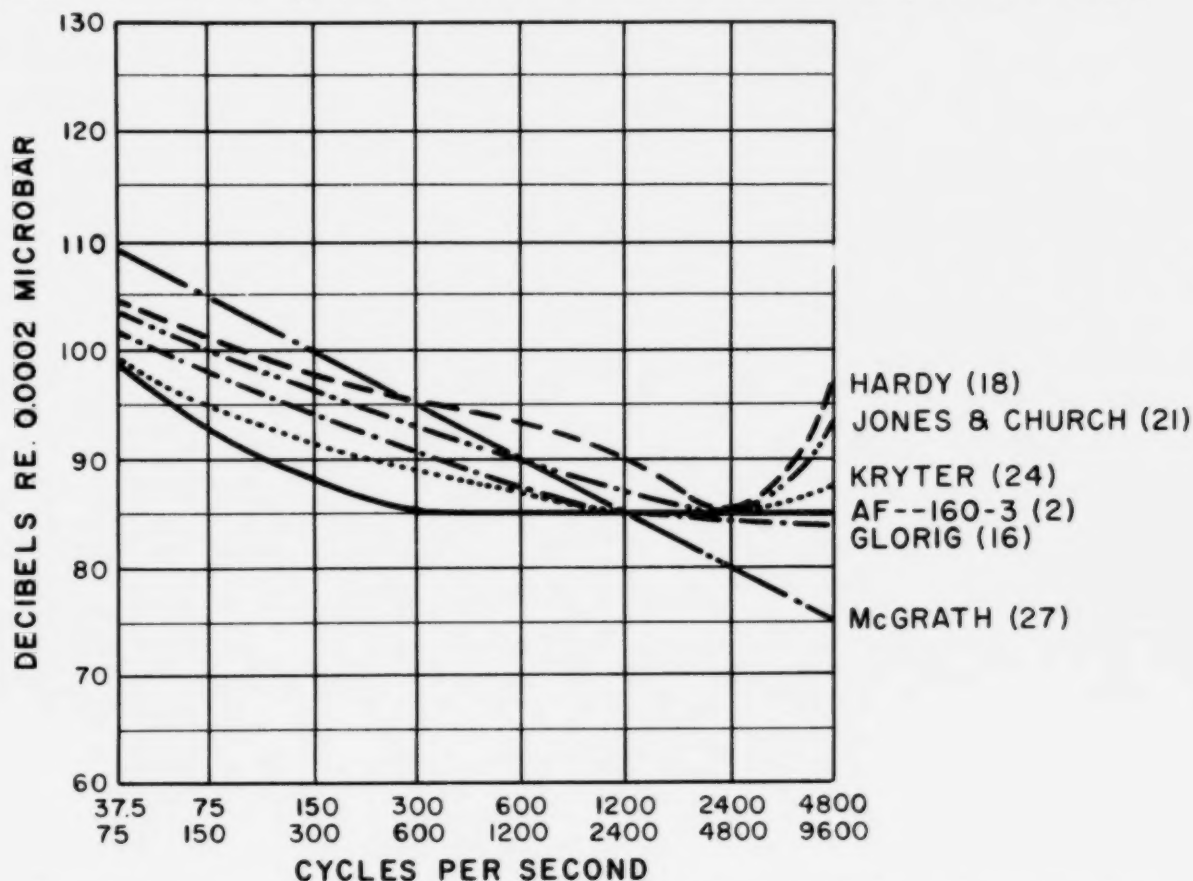


Figure 5. - Proposed limiting octave-band SPL values in dB for safeguarding hearing from continuous 5-8 hour daily exposures to noise for a working lifetime.

Table I**
RELATIONSHIP OF PROPOSED NOISE TOLERANCE CRITERIA TO MEDIAN HEARING LEVEL SHIFTS
AFTER YEARS OF EXPOSURE TO NOISE FOUND IN PRISON INDUSTRIES

Department	Exposure in Years	Median Hearing Level Shifts in Decibels* for Specified Frequencies (in CPS)						Criterion Exceeded
		500	1000	2000	3000	4000	6000	
Cotton Mill (Spin)	4	0.5	0.5	1.0	3.0	2.5	1.0	All except Hardy
Cotton Mill (Twist)	2	1.0	3.5	3.0	12.5	18.0	12.5	All except Hardy
Cotton Mill (Weave)	5	1.5	5.0	6.5	26.0	28.5	20.5	All
Woolen Mill (Spin, Finish)	2	-1.5	-2.5	0.5	8.5	1.0	5.0	None
Woolen Mill (Weaving)	2	1.5	2.0	9.5	14.5	21.5	11.0	All except Hardy
Shoe Factory (Fitting)	4	0.5	4.0	3.0	4.0	6.5	7.0	None
Shoe Factory (Lasting cutting)	3	2.5	1.5	2.0	1.0	1.0	2.5	None
Shoe Factory (Making, Tracing)	4	2.5	2.5	3.0	6.0	5.0	3.5	Glorig
Brush Factory	5	3.0	3.0	5.0	4.5	0.5	20.0	None
Furniture Mills	3	5.5	2.0	2.5	28.0	26.5	25.0	All except Hardy
Furniture (Cabinets)	2	1.0	-1.5	0.0	3.5	10.5	-0.5	None
Printing Factory	3	-0.5	2.0	4.0	2.5	-1.0	2.0	None
Clothing (Tailoring)	3	1.5	2.0	0.5	1.0	-1.0	-1.0	None

*Threshold shift with negative sign indicates hearing is better after exposure than before.

of exposure. Actually, the prison situation was ideal for controlling not only the industrial noise exposure but also the noise occurring when the men were not working. On the other hand, exposures to the industrial noise could not be studied on the same men for more than five years because of the turnover of inmates in the prisons.

Table I summarizes the prison study data, showing the typical shifts in hearing threshold levels (relative to the pre-exposure values) for test frequencies of 500 to 6000 cps following two to five years of exposure to the noise found in the specified work situations. Coupled to the hearing data obtained for each industrial noise situation is a notation (right hand margin) of whether that noise condition exceeded any of the criteria shown in Figure 5. In all instances, a criterion was considered to be exceeded if any one octave band level of the specific noise under observation was greater than the octave limits imposed by the criterion. It is

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indicated that when no criteria are exceeded, the threshold losses at any frequency rarely are more than 10 dB. On the other hand, noise conditions that exceed all of the criteria are associated with quite sizeable shifts, especially for frequencies 3000, 4000, and 6000 cps. As already noted, severe losses at these frequencies mark the early stages of noise-induced hearing loss. With longer exposure to the same conditions, significant losses in hearing would be also expected to occur at lower frequencies where hearing for speech could be impaired. Note that comparatively large threshold losses at high frequencies occur for several noise conditions where all criteria were exceeded with the exception of one (Hardy). This suggests that the limits imposed by this criterion may not always provide sufficient protection against noise-induced hearing loss.

Effects of Noise on Other Physiological Responses

Aside from damage to the hearing mechanism, noise conditions found in indus-

try are not considered to produce any other physiological impairments. Recent reports, however, suggest a tie-up between noise, hearing loss, and cardiovascular disorders although the inter-relationship between these variables is still unclear. Even moderate levels of noise appear to cause constriction in peripheral blood circulation.⁽⁸⁾ The significance of such changes to health has not been determined. Individuals working under intense noise conditions (ball-bearing manufacturing plants) showed some functional disturbances of the cardiovascular system including instability of arterial pressure, slowed heart beat (bradycardia).⁽³⁴⁾ A fatty diet appears to be associated with both circulatory disorders and hearing loss.⁽³⁰⁾ Perhaps hearing loss is due to a reduction in nutriment to the hearing sense organ resulting from noise-induced constriction in blood flow or from a cardiovascular disorder of another origin. Obviously, there is a need for more research in this area.

It should be mentioned that intense noise of sudden onset will cause marked physiological changes including a rise in blood pressure, increase in sweating, changes in breathing, and sharp contractions of muscles in the body. These changes are generally regarded as an emergency reaction of the body, increasing the effectiveness of any muscular exertion which may be required. Although perhaps useful in emergencies, these changes may be harmful for long periods since they would interfere with other necessary activities or produce undue amounts of fatigue. Fortunately, these physiological reactions subside with repeated presentations of the noise.

It has often been stated that in order for performance on a task to remain unimpaired man must exert greater effort in a noisy environment than necessary under more quiet conditions. Measures of energy expenditure, e.g., oxygen consumption, pulse rate, muscle potential, do show changes in the early stages of work under noise conditions which are

indicative of increased effort. With continued exposure, however, these responses return to their normal level.^(15,19)

Intense (or extremely high) levels of sound (over 140 dB) are capable of causing dizziness or loss of equilibrium since the balancing organs (semi-circular canals) are stimulated. Such high intensity exposures may also cause alterations with other types of sensory behavior, and will definitely cause pain, perhaps even traumatic damage in unprotected ears. Examples of such extreme noise conditions are few; possibly in jet engine test cells would these high levels be reached.

Noise and Speech Interference

The most demonstrable effect of noise on man is that it interferes with his ability to use voice communication. A noise which is not intense enough to cause hearing damage may still disrupt speech communication as well as the hearing of other desired sounds. Obviously, such disruption will affect performance on those jobs which depend upon reliable voice communication. The inability to hear commands or danger signals due to excessive noise may also increase the probability of accidents.

Averaging the readings in decibels for the three octave bands 600-1200, 1200-2400, and 2400-4800 contained in a wide-band noise has empirically been shown to provide an indication of the ability of that noise to affect the intelligibility of voice communication. The average of these three octave band dB values is called the speech-interference-level (SIL). In noises whose spectra yield an SIL greater than 75 dB, personnel would have to speak in a very loud voice and use a selected and possibly prearranged vocabulary to be understood over a distance of one foot. Telephone use under these noise conditions would be impossible. Noise conditions having an SIL between 65 and 75

dB would permit barely reliable communication over two feet with a raised voice. This span of communications would be extended to four feet by using a loud voice and to eight feet by shouting. Telephone conversation under 65-75 dB SIL conditions would be difficult. In noise having an SIL between 55 and 65 dB, a normal voice level could communicate effectively over a distance of three feet, a raised voice over a distance of six feet, a very loud voice

over a distance of twelve feet. Telephone use here would be practically unimpaired. An SIL of 55 dB or less would be permissible in large business or secretarial office areas. An SIL of 45 dB or less would be desirable for private offices and conference rooms (see Section on Noise Standards). Figure 6 indicates distance between speaker and listener and voice level restrictions to insure intelligible speech for various SIL conditions.

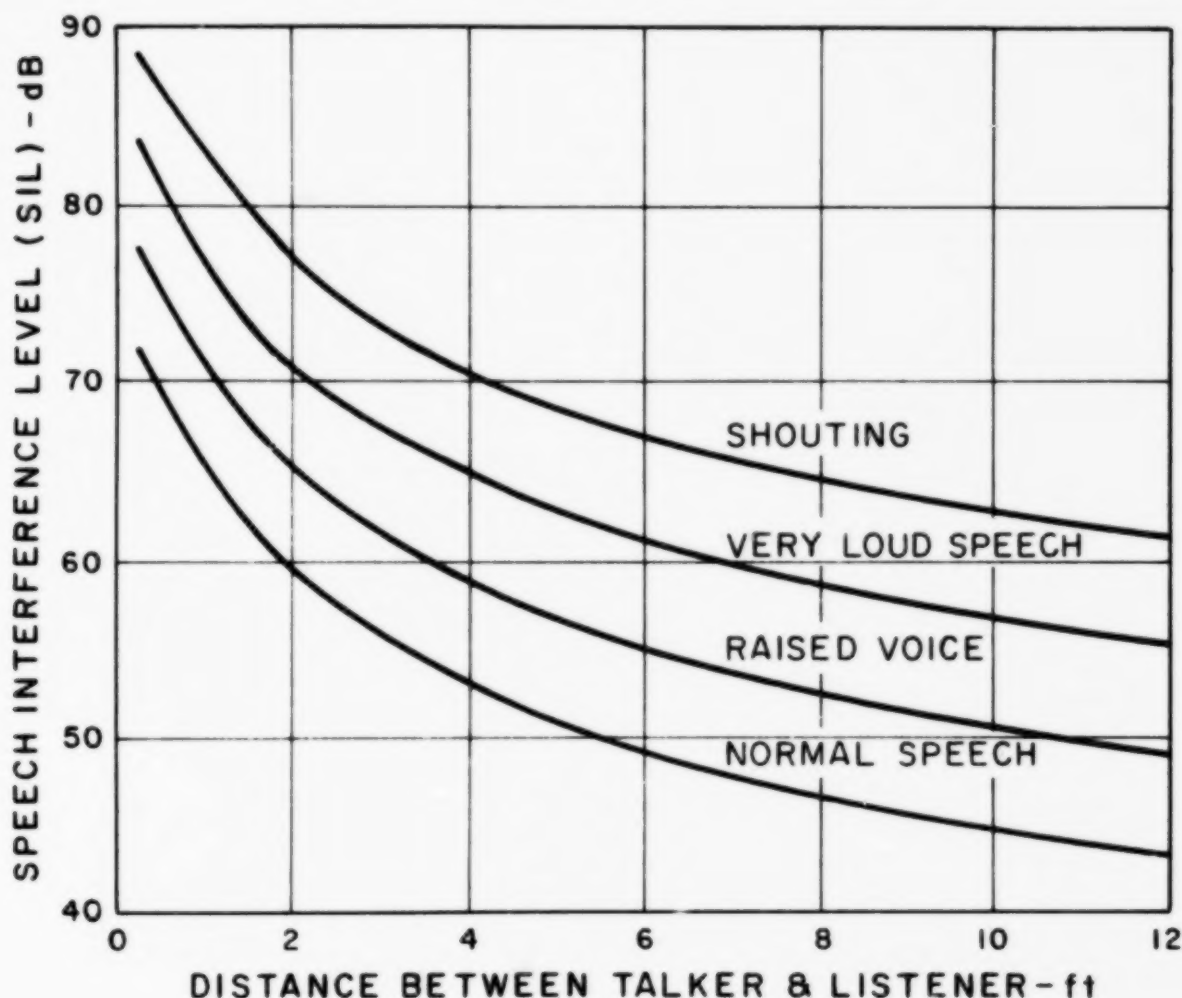


Figure 6. - Voice level and distance conditions needed to insure satisfactory speech intelligibility for specified SIL values. Taken from Bioastronauts Data Book, NASA SP-3006, Nat'l. Aero. & Space Admin., Washington, D.C., 1964 pg. 301.

Impairments in Performance Efficiency)

Contrary to popular thinking, there is little evidence to support the notion that noise degrades performance. Laboratory studies of this problem (summarized in 7, 23) have shown that tasks involving simple, repetitive operations are not affected by noise. Although efficiency in more complex tasks may be initially decreased by noise, such effects tend to vanish as exposure time and/or practice on the task increases. There have been reports, (7, 20, 26) however, which show noise to cause significant losses on vigilance-type tasks. Such tasks require the subject to keep a constant watch over a number of dials or indicators so as to report changes that may occur on any dial at any time. Noise-related losses in vigilance performance are important because of their implications for automated jobs which involve the monitoring of control panels with many indicators displaying information about an ongoing machine process. This finding also has practical importance for jobs requiring the inspection of items passing on a conveyor belt. In such situations a single item must be viewed within a short period of time before passing on to the next.

Field studies concerned with efficiency changes associated with reductions in noise have yielded data that are suspect. Some investigators have noted increased output consequent to noise control treatment in select work areas. (8) This improved performance level was maintained, however, with the restoration of the original noisier conditions. The effects on performance in these cases are probably due to morale changes. That is, the workers see that an interest is being taken in them or their working conditions and

respond with increased effort, leading to greater output. The fact that field studies cannot control factors such as morale, motivation, worker attitudes toward job or supervisor makes it difficult to obtain valid and reliable data reflecting the effects of manipulation of the occupational noise conditions upon performance. (14) For the same reasons, it is difficult to establish cause and effect relationships between industrial noise conditions and accident rate, absenteeism, and employee turnover.

Noise and Annoyance

Perhaps the most widespread reaction to noise is that it is annoying. Whether annoyance types of noise conditions constitute a hazard to health is not known. It has been stated that residents of communities surrounding airports develop hypertension, ulcers, undue anxiety and nervous disorders as a result of the aircraft flyover noise exposure. (1) These effects, however, have never been verified. In fact, studies of communities impacted by aircraft noise show complaints to be motivated by factors that do not bear directly on the health status of the exposed population e.g., interruption in voice conversation (telephone use) and TV reception, personal grievances against the airport management. (6) Such studies, however, have not included a survey of the health of the residents in the impacted area and so do not rule out the possibility that physiological or mental type disorders may stem from such noise conditions.

In any event, judgments of noise-annoyance are complicated by many non-acoustical considerations. Some of these considerations are cited below with examples to illustrate each of them.

Factor

1. The sound has unpleasant associations.
2. The sound is inappropriate to the activity at hand.
3. The sound is unnecessary.
4. The sound has an advantage associated with it.
5. Individual tolerance to noise.

As for the stimulus itself, there appear to be some basic characteristics of sound which can be considered as more annoying than others. These characteristics are as follows:

1. Loudness - the more intense and consequently louder sounds are more annoying.
2. Pitch - a high pitch sound, i.e., one containing high frequencies is more annoying than a low pitch sound of equal loudness.
3. Intermittency and irregularity - a sound that occurs randomly in time and/or is varying in intensity or frequency is judged more annoying than one which is continuous and unchanging.
4. Localization - a sound which originates from several sources or locations is less preferred than one which originates from a single source.

Example

The annoyance caused by the intrusion of aircraft noise into communities around airports is based, in part, upon the residents being fearful of the planes crashing into their homes.

Music tolerated during waking hours may be annoying during the hours of sleep.

People may complain of the noise made by the neighbor's pets, but not by the delivery trucks in the same neighborhood.

The comforts derived from air conditioning outweighs the noise of such units. Similarly, the economic value of nearby plants to a community may balance out the noise produced by the plants; annoyance due to military aircraft noise may be offset by the assurance against surprise attack by an enemy.

Some individuals complain about all kinds of noise as well as other types of nuisances.

At the present time, extensive interest is being directed toward identifying which measure or measures of noise best correlates with annoyance reactions.

For office conditions, speech-interference-level values and loudness-level determinations (these values represent the decibel level of a 1000 cps tone judged equal in loudness to the sound or noise in question) correlate well with subjective ratings of annoyance.⁽⁵⁾

A new measure called perceived noisiness in decibels (PNdB)⁽²²⁾ has been found to agree well with subjective ratings of the acceptability of flyover aircraft noises. This measure takes into account the octave band intensity levels of the noise in question and adjusts them in terms of data showing equal annoyance judgments for different bands of noise. Some noise criteria for airport operations are specified in terms of PNdB. John F. Kennedy Airport

(formerly Idlewild), for example, has a noise ceiling of 112 PNdB for all aircraft operations as measured under the flight path of outgoing or incoming aircraft at one-fourth mile from the end of the runway.

Besides PNdB computations, still other procedures have been proposed to convert the physical measurements of a noise into numerical expressions of annoyance level: Specifically, conversions to loudness measures in sones or phons as developed by Stevens⁽³⁶⁾ or by Zwicker's⁽⁴¹⁾ technique are quite popular for noise annoyance quantification. The assumption in using loudness formulations for rating noise-annoyance is that loudness is the chief determinant in annoyance judgments. Also A-scale sound-level values read directly off a conventional sound pressure-level meter have been frequently used to provide numerical expressions of noise-annoyance conditions.⁽²⁹⁾ Inherent to the A-scale readings as well as the conversion procedures noted are weighing schemes which reflect, in various ways, established relationship between the physical dimensions of sound (primarily frequency and intensity) and associated auditory reactions, both psychological and physiological. (A discussion of the relationships underlying the various conversion procedures is found in References 10, 29, and 41).

It must be emphasized again that the procedures noted above can give only limited prediction of community noise nuisance because they consider only the physical characteristics of the noise stimulus itself. Other factors - social,

personal, economic - must also be taken into account in making such predictions. Several models now exist which consider the physical characteristics of the noise together with known social and psychological factors in estimating the complaint potential of a noise to a community or neighborhood.^(9,35) One of these models is described in Section N-5. The accuracy of the predictions made by this and other models has still not been sufficiently determined.

Summary

Adverse effects of noise on man include temporary and permanent hearing loss, speech disruption, loss in performance capacity, and annoyance. Factors believed critical in evaluating a potential noise hazard to hearing are the overall level, the spectrum of the noise, total exposure duration, time and frequency distribution of short term exposure periods, and susceptibility of an individual's ears to noise-induced hearing loss. Specifications for valid damage risk criteria for noise exposure must take account of these factors. Measures for predicting speech interference of noise are available and have been used as a guide for establishing limiting noise conditions in rooms where effective speech communication is needed. Performance changes and non-auditory physiological changes due to noise have been reported but will require further substantiation. Annoyance reactions to noise are based upon both acoustic and non-acoustic considerations. Models and measures for predicting noise-nuisance are available, but require validation.

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NOISE STANDARDS*

Introduction

Technologic advances in many areas that affect the conditions of daily life have given rise to at least one undesirable by-product -- excessive noise. Factories and offices have become noisier with the introduction of more mechanical and automated equipment. Communities have become noisier because of the spillover of the increasing noise from factories, the flyover of jet and propeller aircraft, and the increased volume of traffic along city streets and the nation's rapidly expanding superhighway systems to mention only a few of the common sources. Homes are also rendered noisier by the increasing use of power appliances, such as garbage disposals, dishwashers, laundry equipment, and air conditioning units.

Noisiness may be defined as a condition induced by unwanted sound. The effects of the noise may be physiological or psychological, the specific response being variable and unpredictable according, in part, to individual susceptibility or adaptability to noise. A noise, therefore, that will produce a large loss of hearing in one individual may produce none in another. A sound that most people would ignore in the industrial part of a city would be a disturbing noise in a quieter environment, such as at night in a residential area or in the country. The annoyance produced by a particular noise may be related to the information it conveys rather than its intensity; as for example, that of a mosquito humming in a bedroom at night, conveying its unpleasant threat.

*Prepared by: Herbert H. Jones for a Master's thesis for the University of Cincinnati.

The physicist or engineer can measure the energy, and the distribution of this energy, within the frequencies making up simple or complex sounds, and can develop subjective scales of loudness with reasonable confidence. Although a particular individual's reaction to such measured sounds cannot be predicted with certainty, statistical analyses of the results of numerous surveys have made it possible to determine how much noise of a particular kind the average inhabitant of a given environment can tolerate without complaint or damage to his hearing. Such data have been used to establish certain criteria as guidelines in establishing acceptable conditions, with respect to noise, for specific purposes. It is, therefore, the purpose of this dissertation to examine the various criteria and to designate levels that will serve as standards to differentiate safe from potentially hazardous levels of noise that may be encountered in daily life in industry or elsewhere.

In order to use these proposed criteria wisely it is necessary to have a basic understanding of the physics and the physiological and psychological effects of noise as well as the techniques for measuring noise.

General Criteria as to the Risk of Loss of Hearing

It has been recognized for many years that certain intensities of continuous noise will produce loss of hearing in an individual so exposed for a sufficient period of time. Loss of hearing due to exposure to industrial noise was recognized as a possibility as early as 1831 by J. Fasbroke.⁽¹⁾ Since that time, numerous surveys of the hearing of industrial workers have been made in both Europe and America. From the published literature, it appears that the majority of the people concerned with establishing standards or criteria were of the opinion, up until about 1950, that a single value for all frequencies

would be adequate for defining a safe level. After about 1950, there was a shift from the single value to those representative of individual octave bands.

A. Criteria Prior to 1950

Representative examples of single values for overall broad-band noise, as published between 1938 and 1950, to differentiate harmful, borderline, and safe levels are given in Figure 1.

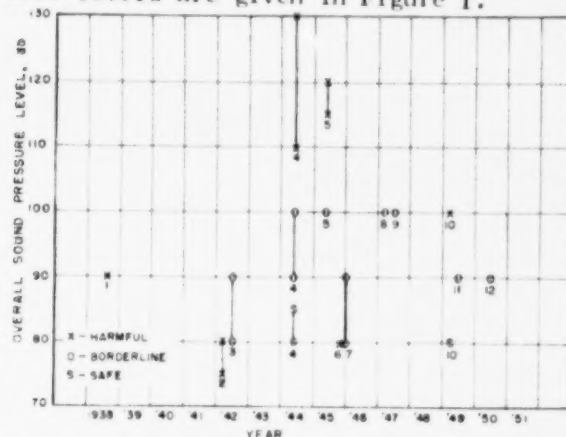


Figure 1. - Single value limits for noise and loss of hearing from the literature, from 1938 to 1950.

No attempt is made to assess the reliability of these values, but brief quotations from some of the original articles will help to establish the significance that the respective authors placed on these values. The numbers identifying the quotation are keyed to the numbers in Figure 1.

1. "Experience indicates that a noise level of 90 decibels or higher is definitely harmful to the human ear. Exposure to prolonged noises of lower level, which is the case with many occupational noises, is also harmful, but the extent of harm done is not well known and cannot be fairly estimated at this time."(2)

2. "It is difficult (to state) the minimum noise level that would be harmful. It appears that as little as 75 or

80 decibels, if sufficiently prolonged, suffice to bring about premature aging of the ears."(3)

3. "The boundary line between noises which cause hearing losses and those which do not, lies between 80 and 90 decibels."(4)

4. "It is probably true that a noise of 80 to 85 decibels will cause some defects of hearing in the high frequency zones after a period of years."(5)

5. "We do not have rigid proof of permanent impairment of hearing by noise of less than 115 or 120 dB ... and concern about exposure to noises below 100 dB ... is probably unwarranted."(6)

6. "A consensus seems to indicate that the minimum safe level is in the neighborhood of 80 decibels, and that an exposure of at least two years is necessary to produce changes at this level."(7)

7. "The boundary line between noises which cause hearing losses and those which do not, seems to lie between 80 and 90 decibels."(8)

8. "The borderline between relatively harmless noise and that which produces steady deterioration lies in the region of 100 dB."(9)

9. "Noise of less than 100 decibels may reasonably be considered quite safe, except perhaps for a few unusually susceptible individuals."(10)

10. "The consensus is that noise levels not exceeding 80 decibels above the normal human threshold cannot be harmful to the human ear ... Exposure of human beings for periods of weeks to noise levels above 100 or 110 decibels will definitely result (in damage)."(11)

11. "For its effect on the hearing function one can, however, safely disregard noise of less than a 90 decibel level."(12)

12. "The guess that is usually made ... is that the upper limit of safety, for factory conditions, is probably about 90 decibels above the threshold of hearing."(13)

The limitations of the single overall level are noticeable from the divergent views expressed above, and it was clear

by the early 1950's that proposed limits must consider other physical characteristics of noise as well as its intensity.

B. Criteria Since 1950

In 1950 K.D. Kryter's now famous monograph on the Effects of Noise on Man was published.⁽¹⁴⁾ This was a comprehensive review of all of the literature on the subject up to that date. Some of the conclusions from this review were:

1. Exposure to intense noise from machinery may cause partial and temporary hearing losses that persist for a few minutes to several hours.
2. Repetitive exposure over extended periods (years) may result in a permanent partial deafness.
3. The more intense the sound the greater the deafening effect.
4. The maximum intensity at which no deafening effect will occur is probably in the neighborhood of 85 decibels above 0.0002 dynes/cm² for "critical bands" of noise.
5. The overall intensity of a noise, as expressed in decibels, will not, as a rule, indicate its deafening effect.

The author recognized a need to consider the component frequencies and the widths of bands of frequencies that have common effects in evaluating the hazard of a given exposure to noise. Nearly all of the criteria advanced since the appearance of this monograph have reflected Kryter's concepts. The limits proposed by Kryter and other investigators are shown in Table I.

H.C. Hardy in a paper published in 1952 concluded "...the spectrum level which exceeds 100 sones* per octave band is very probably damaging for long time daily exposure. For occasional exposures, spectrum levels of perhaps 200

* A unit of loudness, by definition, a simple tone of 100 cycles per second, 40 decibels above a listener's threshold, produces a loudness of 1 sone. The loudness of any sound that is judged by the listener to be n times that of the 1 sone tone is n sones.

sones or more are probably safe. All evidence indicates that when no octave band level exceeds 50 sones, there is very little likelihood that hearing damage will accrue, even when the daily exposure persists over many years."⁽¹⁵⁾ This was the first time that a hazardous "zone" of noise instead of a single level had been formally presented in the literature. Within this zone there was a very slight hazard at the lower limit to an almost certain hazard at the upper limit.

In 1953, W.A. Rosenblith and K.N. Stevens pointed out some of the difficulties in arriving at a safe level for exposure to noise.⁽¹⁶⁾ Most groups attempting to establish standards of safety for various levels of noise at that (circa 1953) time set target goals which required that the hearing threshold levels, as measured with pure tone in a noise-exposed population, should not differ significantly from those of a matched control population. The concepts of monitoring audiometry had not been fully developed when this criterion was written, and most investigators were striving for limits that would provide complete protection of hearing. Rosenblith and Stevens recognized that it would be difficult to know when complete protection had been achieved, since the threshold shifts associated with the normal aging process (presbycusis) are not always distinguishable from the threshold shifts produced by exposure to noise. Furthermore, among persons not exposed to noise, presbycusis varies greatly, and the threshold shifts due to age and other causes may be as great as those caused by exposure to high levels of noise.

Rosenblith and Stevens decided further that levels of noise should be measured in octave bands and applied as long as the spectrum of the noise was relatively uniform. The assumptions made by Rosenblith and Stevens are listed below because they are considered as essential and complementary to the limits of exposure to noise that they proposed.

Table I

Criteria of Risk of Auditory Damage, as Proposed from 1950 to 1963

Author	Reference	Year	Level of Sound Pressure in Octave Bands									
			20- 75	75- 150	150- 300	300- 600	600- 1200	1200- 2400	2400- 4800	4800- 9600		
Kryter	14	1950	--	120	110	96	95	95	88	100		
Hardy, 100 Sones	15	1952	115	112	108	106	104	95	91	102		
Hardy, 50 Sones	15	1952	104	100	97	95	92	87	85	95		
Rosenblith and Stevens - Broad-band	16	1953	110	102	97	95	95	95	95	95		
Rosenblith and Stevens - Narrow-band	16	1953	100	92	87	85	85	85	85	85		
AFR 160-3	17	1956	--	--	--	85	85	85	85	--		
AACO	18	1957	--	--	--	85	85	--	--	--		
ISO	19, 20	1961	103	96	91	88	85	83	81	80		
Kryter - Broad-band	21, 22	1963	--	98	92	89	86	85	85	86		
Kryter - Narrow-band	21, 22	1963	--	93	87	84	81	80	80	81		
AACO	18	1964	--	--	--	85	85	85	--	--		

1. The values are not to be taken too literally, since deviations of the order of 1 or 2 decibels in either direction can probably be disregarded. The values should be used as zones because of the uncertainties involved in assessing exposure and the differences in individual susceptibility to damage from exposure to noise. The authors believed, however, that contours 10 decibels lower would involve negligible risks, whereas contours 10 decibels higher would result in significant increases in hearing loss.
2. The standard levels were to be considered safe for occupational exposure, under the usual conditions, throughout the occupational lifetime.
3. The standard levels were to apply to exposure to noise that is characterized by reasonably uniform occurrence in time.
4. For noise composed of wide bands, the numbers designated "octave bands" should be used. For pure tones, or for noise in which the major portion of the energy is concentrated in a band narrower than the critical band, the values designated for "critical bands" were to be used.
5. The standard should be considered as tentative only, and subject to further revision as new laboratory and field data are developed and reported.

One of the most important contributions of Rosenblith and Stevens was their statement of the statistical nature of the relation between exposure to noise and loss of hearing. They also introduced a clearer concept of specific goals for the criteria.

In 1956 the United States Air Force instituted a hearing conservation program that included monitoring audiometry. The mechanism for carrying this out was

defined in Air Force Regulation (AFR) 160-3, "Hazardous Noise Exposure."⁽¹⁷⁾ The goal was the preservation of hearing so that no one sustains a heavy loss of more than 15 decibels for pure tones at test frequencies of 500, 1000, and 2000 cycles per second. From available information it was determined that, except on rare occasions, there would be a negligible hazard if the established standards were not exceeded in any of the four octave bands between 300 and 4800 cycles per second. The regulation recommended the application of "auditory protection" when the sound pressure level* exceeded 85 decibels in any one of the four octave bands and made such protection mandatory when the sound pressure in any of the octave bands exceeded 95 decibels. These limits were applied to continuous exposure, 8 hours in duration. Limits were also established for shorter periods of exposure, based on the assumption that the loss of hearing was directly proportional to the total acoustical energy, regardless of how this energy was distributed in time. Since, on the decibel scale, a doubling of the energy results in an increase of 3 decibels, the allowable sound pressure level could be increased by 3 decibels if the duration of exposure was cut in half. One advantage of the equal-energy rule was the elimination from the hazardous category of many types and occasions of brief exposure to noise of high intensity. Air Force Regulation 160-3 employed the more important features of the Rosenblith and Stevens criteria and, in addition, specified the use of monitoring audiometry to determine whether those who were exposed to noise were developing actual incurred losses of hearing. The Regulation also promulgated limitations for exposure to noise for periods less than 8 hours per day.

The Subcommittee on Noise of the Committee on Conservation of Hearing of the American Academy of Ophthalmology

* Sound pressure level as defined in the American Standards Association, in S1.1-1960, American Standard Acoustical Terminology.

and Otolaryngology issued a "Guide for Conservation of Hearing in Noise" in 1957.⁽¹⁸⁾ The Subcommittee shared the implied goal of the parent committee and, accordingly, chose to write a limited criterion that emphasized safety, rather than the acceptance of potential hazard. Their statement reads, "If the sound energy of the noise is distributed more or less evenly throughout the 8 octave bands, and if a person is to be exposed to this noise regularly for many hours a day, 5 days a week for many years, then: if the noise level in either the 300-600 cycle band or the 600-1200 cycle band is 85 decibels, the initiation of noise-exposure control and tests of hearing is advisable. The more the octave band levels exceed 85 decibels the more urgent is the need for hearing conservation." Periods of short exposure and of exposure to noises of impact or those composed of narrow

bands were specifically excluded from this criterion.

In 1961 the Technical Committee 43 - Acoustics of the International Organization for Standardization (ISO) proposed "Noise Rating Numbers with Respect to Conservation of Hearing, Speech Communication and Annoyance."⁽¹⁹⁾ In this standard, a system of Noise Rating Numbers (N) was proposed in which (N) may be calculated from the following formula:

$$L = a + b N$$

Where:

L = noise level of octave band in question in dB

a and b = coefficients as functions of the mid-frequencies of the octave bands. (See Table II).

The family of curves generated by using this equation is shown in Figure 2.

Table II

The Coefficients a and b in the Equation $L = a + b N$, as a Function of the Mid-Frequencies of the Octave Bands

Mid-Frequencies of the Octave Band cps	a dB	b dB
63	35.5	0.790
125	22.0	0.870
250	12.0	0.930
500	4.8	0.974
1000	0	1.000
2000	-3.5	1.015
4000	-6.1	1.025
8000	-8.0	1.030

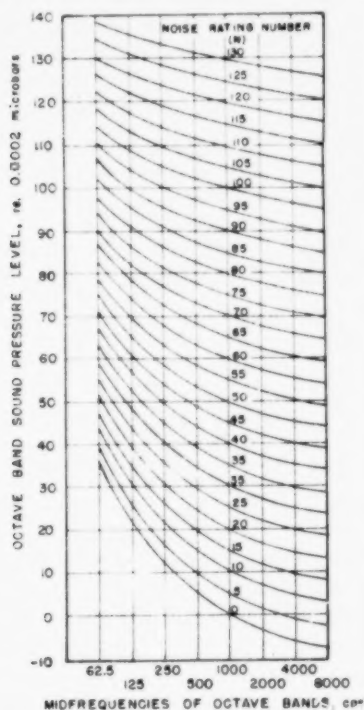


Figure 2. - International Organization for Standardization (ISO), Noise Rating Curves.⁽²⁰⁾

When exposure to noise composed of broad bands is habitual, and the noise is continuous during the working day (5 or more hours), N85 is proposed as a limit for conservation of hearing because habitual exposure to such a noise for 10 years may be expected to result in a negligible loss in hearing for speech by the average individual. Such a level, from the point of view of conservation

of hearing in industrial situations is often considered to be "just allowable," but a somewhat more or less rigorous criterion may be appropriate in other situations or jurisdictions.

This proposed standard also makes use of the "equal energy concept," as applied to shorter periods of exposure to higher levels of noise. That is, when the duration of exposure is reduced by half, the noise rating number can be increased by 3 decibels as shown in Figure 3.

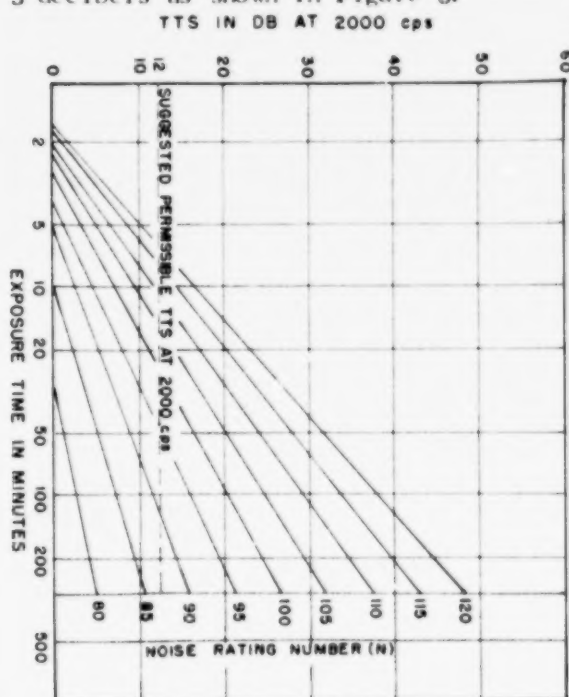


Figure 3. - International Organization for Standardization (ISO) Numbers for rating noise for brief periods of exposure to noise.(20)

In the equal energy concept it is assumed that a noise which will produce a temporary shift in threshold (TTS), or a temporary loss of hearing, will produce a permanent shift in threshold (PTS), or permanent loss of hearing of the same magnitude, if the exposure continues for many years. The observations of the laboratory seem to verify the equal energy concept.

In addition, a criterion was proposed for intermittent exposure as follows: "When habitual exposure is to broad-band noise that is intermittently on during the working day, the permissible noise rating number of the noise in question may be obtained by use of Figure 4.

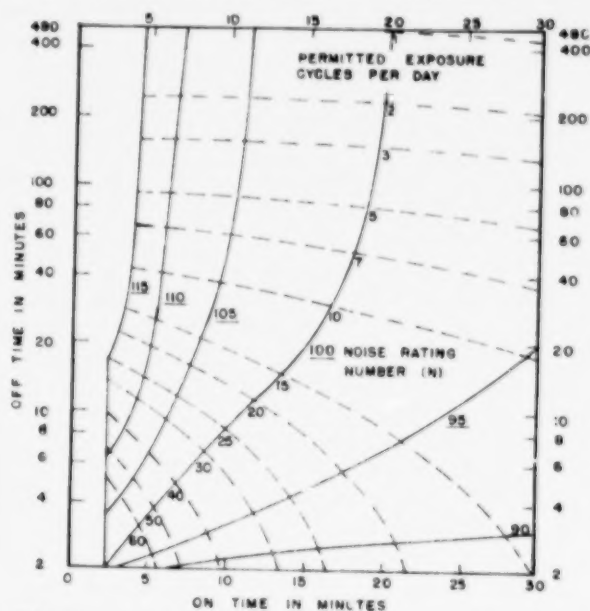


Figure 4. - International Organization for Standardization (ISO) Numbers for rating noise from intermittent exposure to noise.(20)

This figure shows the relationship between the duration of noise bursts (abscissa), the 'off-time' between noise bursts (ordinate), the number of such cycles of noise and relative quiet (broken contours) and the noise rating number (solid contours) that the noise would have if it were on continuously. Each of these contours is the locus of combinations of "on-time" and "off-time" and, for the noise it represents, it gives a limit of exposure equivalent to that prescribed for a continuous noise with a rating number of 85. This criterion may be used as follows: Assume that there is a noise that persists for 10 minutes and produces a level of N 100, as determined from Figure 4, after which the noise is discontinued for 8 minutes; entering the

abscissa at 10 minutes of duration and the ordinate at 8 minutes of discontinuance, it turns out that this exposure can be repeated on 25 occasions within an 8-hour day, being equivalent, thereby, to a continuous exposure to N 85. This criterion follows that proposed by A. Glorig, W.D. Ward, and J. Nixon in 1961. (20)

During 1963, K.D. Kryter proposed a criterion for exposure to noise, in terms of the impairment of speech communication, as the result of noise-induced deafness. (21) This criterion permits any exposure to noise that, on the average, produces a temporary shift in threshold of a set number of decibels at 3 frequencies, when measured 2 minutes after the termination of exposure. The permissible shifts are no more than 10 decibels at 1000 cps or below; 15 decibels at 2000 cps; or 20 decibels at 3000 cps or above. It is thought that daily exposure to such noise for about 10 years will produce permanent hearing losses of similar magnitude. The criteria, for continuous exposure for 8 hours or less per day, as shown in Figure 5, are the same as those contained in the draft of a Technical Report of the Armed Forces - National Research Council Committee on Hearing and Bio-Acoustics being prepared for the Surgeon General of the U.S. Army. (22)

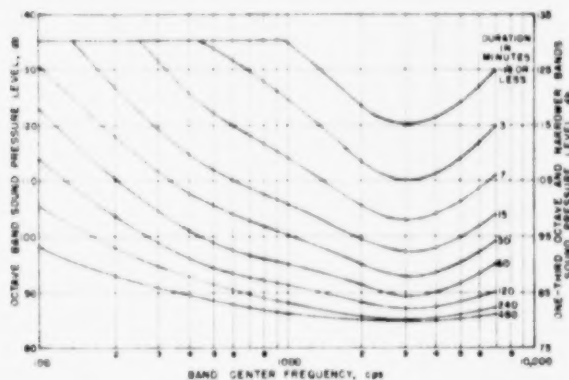


Figure 5. • Sound pressure levels required for octave bands (left-hand ordinate) and one-third or narrower (right-hand ordinate) of noise of different center frequencies to achieve criteria of risk associated with duration as the parameter (K. D. Kryter). (21)

In 1964 the Subcommittee on Noise, of the Committee on Conservation of Hearing of the American Academy of Ophthalmology and Otolaryngology, revised their publication "Guide for Conservation of Hearing in Noise." (18) The following limits for exposure to noise were given:

- (1) When the exposure to broad-band noise is habitual and the noise is continuous during the working day (5 or more hours) the average of the levels at 300-600, 600-1200, and 1200-2400 c/s should not exceed 85 dB. If this average exceeds 85 dB, hearing conservation measures should be initiated.
- (2) When the exposure to broad-band noise is habitual and the noise is continuous for less than 5 hours per day, Table III should be consulted for recommended allowable exposures."

Table III

Average level of 300-600, 600-1200, and 1200-2400 c/s bands	On-time per day (minutes)
85 dB	less than 300
90 dB	less than 120
95 dB	less than 50
100 dB	less than 25
105 dB	less than 16
110 dB	less than 12
115 dB	less than 8
120 dB	less than 5

The Committee also recommended the application of the criteria proposed by the International Organization for Standardization, to intermittent exposure to noise, as shown in Figure 4.

Up to the present time, criteria have been proposed for continuous exposure to noise for 8-hours or less per day or for cycles of noisy and noiseless

periods of time. No criteria have been established for impulse-type noises. The present state of knowledge concerning impulse-type noise has been summarized by Glorig, Ward, and Dixon as follows: "Our very limited knowledge of the effects of impulsive noise prevents any meaningful discussion of impulsive-type noise exposure." (19)

Noise in Buildings

In the design of buildings, or rooms within buildings, it is necessary to know the highest levels of noise that neither disturb the occupants nor impair their efficiency while at work. The design chosen depends, to a large extent, on the nature of the noise, and on the type and customary use of the room or building. The fluctuation of the noise with time is one of the factors which determines whether a noise is tolerated. For example, a bedroom with an average level of noise of 45 decibels, with instantaneous peaks substantially no higher than this value, would be more conducive to sleep than would a room with an average level of only 35 dB, in which the stillness is pierced by an occasional loud shriek. It must be remembered also that noise that is annoying to one person may be unnoticed by another. It is impossible, therefore, to specify precise values that will be acceptable to all individuals, but it is useful to know the range of average levels of noise that are acceptable under average conditions.

Over the years, a number of criteria have been developed for predicting the acceptability of the acoustical environment in various occupied spaces. These criteria are based on various scales of subjective rating which have been developed from both research in the laboratory and experience in the

field. The scales include levels of speech-interference, loudness, perception of noise, curves expressive of criteria as to noise, and numerical ratings of noise.

A. Levels Associated with Interference with the Hearing of Speech (Units = dB)

Speech Interference Levels (SIL), as they are commonly known, are the arithmetic averages of the readings, in decibels, in the 3 octave bands: 600 to 1200, 1200 to 2400, and 2400 to 4800 cycles per second. The resulting number, in decibels, is a useful guide to the interference of noise with the hearing of speech. The "Speech Interference Level" criterion was first proposed by L.L. Beranek⁽²³⁾ and by L.L. Beranek and H.W. Rudmose.⁽²⁴⁾

Such levels (i.e., SIL) are obtained by using the "slow" scale (a highly damped circuit) on the octave-band analyzer and determining the average sound pressure levels of the noise in the bands 600 to 1200, 1200 to 2400, and 2400 to 4800 cycles per second. The arithmetic average of the sound pressure level in these 3 bands is the speech interference level.

If 2 men are standing facing each other in the field of noise, the maximum SIL that just permits reliable communication at various intensities of noise and at various distances is shown in Table IV. In making up this table, average male voices, good hearing, as well as unfamiliar word material are assumed. If the vocabulary is limited, or if sentences only are spoken, the permissible level for interference with speech may be increased by about 5 decibels. If a woman is speaking, the permissible levels should be decreased by about 5 decibels.

Table IV

Speech Interference Levels (in decibels re 0.0002 microbar) that Barely Permit Reliable Word Intelligibility at the Distances and Loudness of Voice Indicated. No Reflecting Surfaces to Aid Direct Speech are Assumed.*

Distance Feet	Voice Level (Average Male)			
	Normal	Raised	Very Loud	Shouting
0.5	71	77	83	89
1	65	71	77	83
2	59	65	71	77
3	55	61	67	73
4	53	59	65	71
5	51	57	63	69
6	49	55	61	67
12	43	49	55	61

*After L.L. Beranek, Reference 23

It must be emphasized that the level of speech interference for a noise at a particular location does not predict how intelligible speech will sound to a listener at that location, because it does not describe the sound pressure level of the speech itself.

In offices, satisfactory communication by speech is often the principal reason for the control of noise. In a survey of manufacturing companies and of an educational institution, Beranek and Newman found that, when office workers were asked to rate noise on a scale ranging from "very quiet" to "intolerably loud" they did so in approximate accordance with the degree of interference with the hearing of speech. (25) The results are shown in Figure 6. The noise ratings are shown on the vertical scale, the speech interference levels on the horizontal scale, and the area so defined, within which a telephone can be used satisfactorily, is marked by the upper horizontal scale.

When questioned, employees said that Point A, in Figure 6, corresponded to a slightly raised voice at 3 feet. Comparison of the statements with the numbers in Table III indicated that the employees desire speech interference

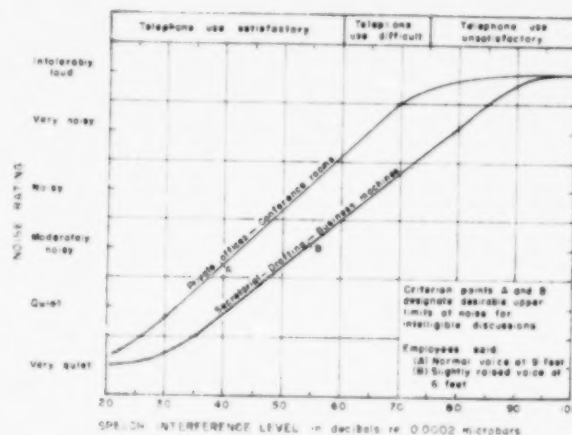


Figure 6. - Rating scale for noise in office spaces, as a function of speech-interference level (L.L. Beranek and R.W. Rudmose). (24)

levels about 6 dB lower than those in the table. The rating scale for telephone conversation, shown along the top of Figure 6, is based on intercity calls using the F-1 telephone set (not the latest set with the numbers outside the dial). For calls within a single modern exchange the permissible levels of speech interference are about 5 dB greater than those shown. For the latest

model telephone set, intra-exchange and intercity conditions are generally the same.

Maximum permissible levels of speech interference also have been suggested for various types of rooms, and are shown in Table V. These levels were based on measurements made when the room was not in use.

Table V

Maximum Permissible Speech Interference Levels for Rooms. Measurements Made while Room not in Use(25)

Type of Room	Maximum Permissible Level
Small private office	40
Conference room for 20	30
Conference room for 50	25
Movie Theater	30
Theater for Drama (500 seats, no amplification)	25
Coliseum for sports only (amplification)	50
Concert Hall (no amplification)	20
Secretarial offices (typing)	55
Homes (sleeping area)	25
School rooms	25

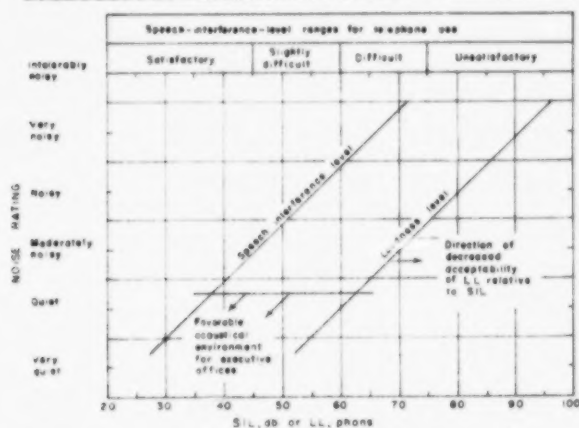


Figure 7. - The relation of the subjective ratings of executive-office personnel to SIL and LL, and office personnel's ratings of satisfactory use of telephone as related to SIL (L.L. Beranek). (26)

B. Levels of Loudness (Units = Phons)

The loudness level* (LL) of a particular sound or noise, expressed in phons, is generally defined as the sound pressure level of a tone of 1000 cps that is equivalent in loudness to the sound or noise being rated. As used in this paper, however, the loudness level is computed from the levels of the octave band, since the computed level is employed most frequently in work involving the control of noise.

L.L. Beranek found that errors resulted in some situations when the speech interference level was used to predict the response of office workers to various noises. (26) The results of a series of ratings of noise by office workers are plotted against the corresponding speech interference level and loudness level in Figures 7 and 8. Figure 7 gives the results for executive offices and small conference rooms, and Figure 8 exhibits the results for stenographic and large engineering drafting rooms.

* As defined in the American Standards Association, in S1.1 -1960, American Standard Acoustical Terminology.

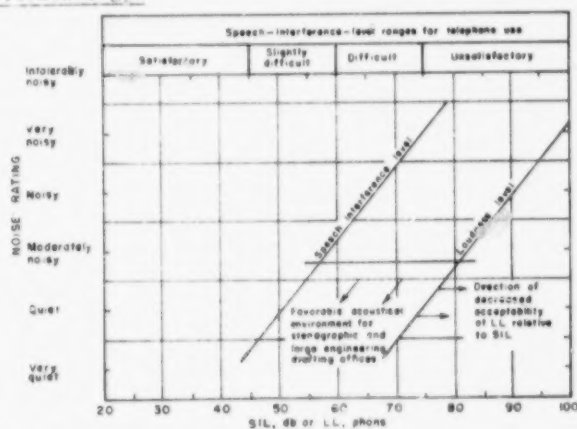


Figure 8. - The relation of the subjective ratings of noise to SIL and LL for stenographic and large engineering drafting rooms and office personnel's ratings of the satisfactory use of telephone as related to the SIL (L.L. Beranek). (26)

The left hand ordinate of Figure 7 shows the rating scale used on the questionnaire given to the office workers. On the average, the personnel in executive offices thought that the noise should not exceed a rating of just below "moderately noisy" if their work was not to suffer. More than half of those questioned said that, if the room were more than moderately noisy, their ability to use the telephone and to converse with co-workers would be affected. Nearly all of them said that they used the telephone "often" to "very often," and that they conversed "often" with co-workers as far away as 8 to 10 feet. It follows then, that the SIL in executive offices should not exceed about 40 dB, if conversations are to be carried on in a more or less normal tone of voice over distances of 8 to 10 feet.

In some offices the subjective ratings correlated better with the computed loudness level (LL) than with the measured Speech-Interference Levels. Examination of the spectra of the octave-bands measured in these offices revealed that more of the sound energy was in the lower frequencies below the speech range than was found to be in the offices, in which the subjective ratings correlated well with both the SIL and LL.

Where the correlation with both LL and SIL was good, the LL in phons was not much more than 22 units higher than the SIL in decibels. Whenever the difference between LL and SIL became substantially greater than 22 units, for example, 30 units, the subjective rating was higher than would be predicted by the SIL alone. In addition, when the

difference between the loudness level and the SIL exceeded 30 units, complaints usually occurred, even when the SIL met the requirement of being lower than 40 dB.

For the reasons just cited, the acceptable LL, as plotted in Figures 7 and 8, is about 22 units to the right of the SIL. If the difference between the two curves exceeds 22 units, the noise level is likely to be found less acceptable than would be predicted by the SIL alone. These observations, therefore, show that neither the SIL nor the LL alone is sufficient to characterize the critical spectrum in all situations; in some bases both levels are needed.

C. Application of Curves to the Criteria as to Noise

A family of curves representing criteria as to noise has been developed by L.L. Beranek to be used in evaluating noise in offices and rooms.⁽²⁷⁾ These ratings are based on investigations not aimed at determining, quantitatively, the effects of noise on the efficiency of office workers, but rather at determining the maximum level of noise at which office personnel feel that they can accomplish their duties without loss of efficiency.

These criteria are more detailed than those concerned with loudness, per se, or interference with speech. The criteria have been developed over a number of years, the first set of curves being called, "Speech Communication" (SC) criteria were proposed in 1953 by L.L. Beranek, J.L. Reynolds, and K.E. Wilson.⁽²⁸⁾ These curves have been modified from time to time and are presently used in the form shown in Figures 9 and 10 and in Table VI.^(26, 29)

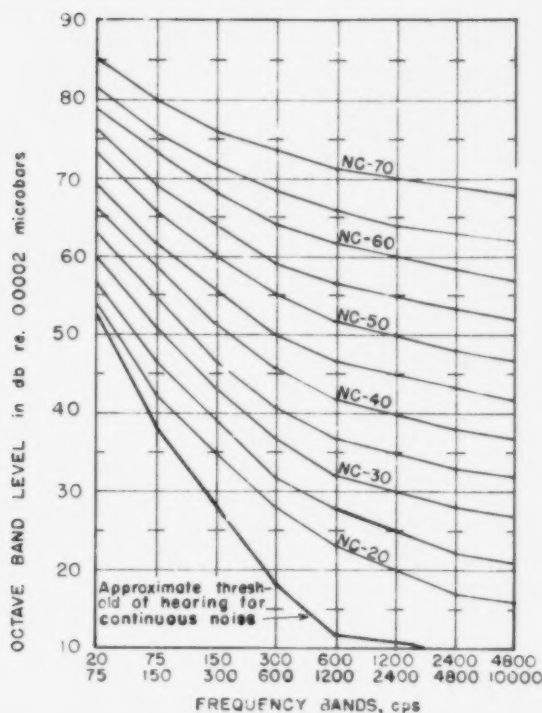


Figure 9. - Curves of criteria for use with Tables V and VI in determining the permissible (or desirable) sound pressure level in eight octave bands. These curves are recommended for specifications wherever a favorable relation between the low-frequency and the high-frequency portion of the spectrum is desired. Each NC curve has an LL in phons that is 22 units greater than the SIL in decibels (L.L. Beranek).⁽²⁷⁾

The "Noise Criteria" (NC) curves of Figure 9 are a family of curves, such that the SIL in decibels is the same as the NC number written on the curve, and the LL in phons is 22 units greater than the "Speech Interference Level." In Figure 10, an alternate family of curves (NCA) is presented, in which the LL is greater than the SIL by 30 units. The NC curves are recommended for use in all spaces. The NCA curves are recommended for use only where a maximum compromise due to economic factors is necessary.

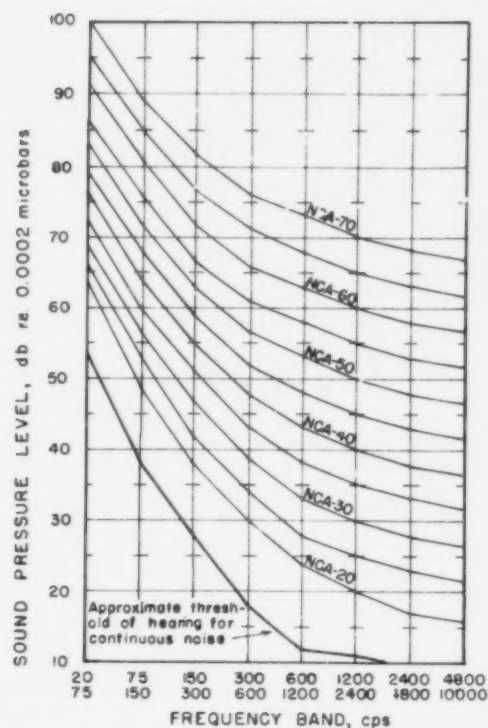


Figure 10. - Same as for Figure 9 except that each NCA curve has an LL in phons that is 30 units greater than the SIL in decibels. These curves may be used in specifications in place of those of Figure 9 whenever economy dictates a maximum compromise and where, in addition, the noise is steady and free of beats between low frequency pure tone components (L.L. Beranek).⁽²⁷⁾

The use of the NC curves has been extended to other interior spaces. The recommended levels are shown in Table VII. In using these criteria one must remember that local situations and local attitudes affect the critical response or attitude of people. Levels that seem adequate in one location may invoke complaints in another. Although there is variability, the NC curves can be and are being used successfully in specifications at the present time.

Table VI

Recommended Criteria as to Noise in Offices

Measurements made for the purpose of judging the tolerability of the noise in an office, by comparison with these criteria, should be performed with the office in normal operation, but with no one talking at the particular desk or conference table where communication through speech is desired (i.e., where the measurement is being made). Background noise with the office unoccupied should be lower, by about 5 to 10 units.

NC Curve of Figure 9	Environment of Communication	Typical Applications
NC-20 to NC-30	Very quiet office - use of telephone satisfactory - suitable for large conferences.	Executive offices and conference rooms for 50 people.
NC-30 to NC-35	"Quiet" office, satisfactory for conferences at a 15 foot table; normal voice 10 to 30 feet; use of telephone satisfactory.	Private or semi-private offices, reception rooms, and small conference rooms for 20.
NC-35 to NC-40	Satisfactory for conferences at a 6 to 8 foot table; use of telephone satisfactory; normal voice 6 to 12 feet.	Medium-sized offices and industrial business offices.
NC-40 to NC-50	Satisfactory for conferences at a 4 to 5 foot table; use of telephone somewhat difficult, occasionally normal voice 3 to 6 feet; raised voice 6 to 12 feet.	Large engineering and drafting rooms, etc.
NC-50 to NC-55	Unsatisfactory for conferences of more than 2 or 3 people; use of telephone slightly difficult; normal voice 1 to 2 feet; raised voice 3 to 6 feet.	Secretarial areas (typing), accounting areas (business machines), blueprint rooms, etc.
Above NC-55	"Very noisy;" office environment unsatisfactory; use of telephone difficult.	Not recommended for any type of office.

D. Requirements as to Insulation Against Sound-Building Codes

Many of the world's major nations, with the exception of the United States, have regulations concerning minimum requirements for the insulation of buildings against sound. For a number of years, European countries have promulgated minimum requirements for insulating structures against airborne sound, and have prescribed minimum losses in the transmission of impact sound through floors and ceilings. A paper by D. Brandt, published in 1964, discusses the development and uses of the European building codes.⁽³¹⁾ A comparison of typical requirements for the insulation of airborne sound in a number of nations is given in Figure 11. A comparison of

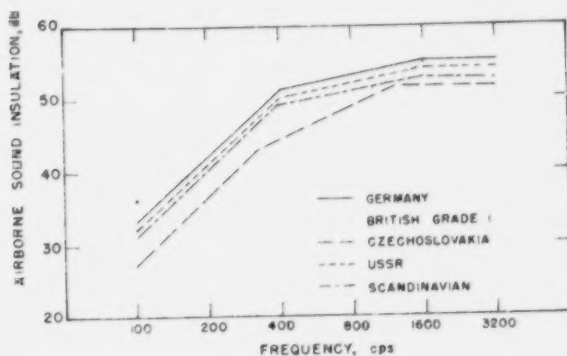


Figure 11. - Comparison of typical national requirements for insulation of airborne sound for multidwelling buildings (O. Brandt).⁽³¹⁾

the requirements of a number of nations for the minimum of loss in the transmission of impact noises through floors and ceilings, is given in Figure 12. When building codes are prepared in the United States incorporating requirements for sound insulation, it is believed that these will be patterned after the European codes. These codes

will serve as satisfactory guides until standards have been developed in the United States.

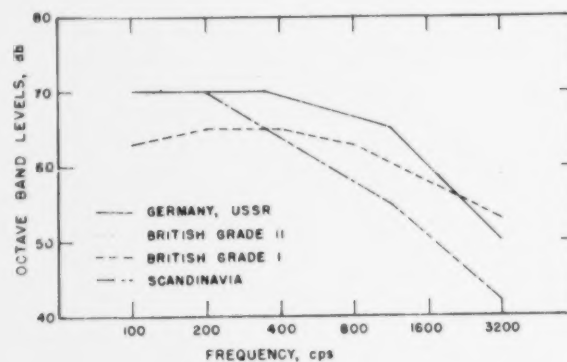


Figure 12. - Comparison of typical national requirements for control of transmission of impact sound in multidwelling buildings (O. Brandt).⁽³¹⁾

There have been increasing complaints of disturbances by noise in this country, and because of this the Federal Housing Administration (FHA) has included recommendations for the control of noise in their "Guide for Minimum Property Standards." A study of existing codes and several surveys of public reaction to household noise have led to

- (1) the recommendation of a criterion of acceptability for floor and ceiling construction in multifamily dwellings;
- (2) a list of floor and ceiling structures commonly used in the U.S.A., classified according to their ability to meet the criterion; and
- (3) a set of recommendations and suggestions regarding important structural details.

These are presented in a Guide published by FHA in January 1963. They were discussed by T.J. Schultz in a paper published in 1964.⁽³⁰⁾ The recommendations relative to the transmission of sound through floors and ceilings, as recommended by FHA, are shown in Figure 13.

Table VII

Recommended Criteria as to Noise in Rooms

Levels of noise are to be measured in unoccupied rooms. Each curve representative of a criterion noise is a code for specifying permissible levels of sound-pressure in eight octave bands. It is intended that the specified level should not be exceeded in any one frequency band. The computed equivalent dBa numbers in the right-hand column are presented for information only, and are not recommended for use in specifications. Ventilating systems should be operating and outside sources of noise, traffic conditions, etc., should be normal, when measurements are made.

	Recommended Noise Criterion Curve of Figure 9 or Figure 10	Computed Equivalent Sound-Level Meter-Readings* Weighting Scale A (dBa)
Broadcast studios	NC 15-20	25-30
Concert Halls	NC 15-20	25-30
Legitimate theatres (500 seats, no amplification)	NC 20-25	30-35
Music rooms	NC 25	35
Schoolrooms (no amplification)	NC 25	35
Television studios	NC 25	35
Apartment and hotels	NC 25-30	35-40
Assembly halls (amplification)	NC 25-30	35-40
Homes (sleeping areas)	NC 25-35	35-45 +
Motion picture theatres	NC 30	40
Hospitals	NC 30	40
Churches	NC 30	40
Courtrooms	NC 30	40-45
Libraries	NC 30	40-45
Restaurants	NC 45	55
Coliseums (for sports only, amplification)	NC 50	60

*If there were relatively less noise in the low-frequency bands than indicated by the recommended noise criterion curve, the dBa numbers would be lower by about 5 dBa. All numbers in this column should be dropped by 5 dBa, if they are to be used to estimate the compliance of a normally encountered noise level with an NC criterion; these numbers should not be used for purposes of preparing specifications.

+Room air conditioners manufactured prior to 1957 commonly produce levels of 40 to 55 dBa in sleeping areas.

Criteria for Noise in the Community

Technologic advances also have resulted in more noise in the community from factories, jet and propeller aircraft, and vehicular traffic on city streets and the nation's rapidly expanding system of superhighways. This noise induces reactions that vary from mild to severe - involving legal action in some cases. Those who are responsible for creating the noise would, naturally, like to avoid the litigation. In order to maintain the goodwill of the neighborhood they are, in most situations, willing to put forth considerable effort in controlling the noise.

Data relative to many situations have been obtained and analyzed in order to put the control of noise in the community on a systematic basis. It has been found that the reactions of residents cannot be predicted on the basis of specific measurements or even on computed loudness ratings, but that many factors enter into this problem.⁽³²⁾ In addition to the range of reactions to be expected from different individuals, other factors include: the level and spectrum of the noise; whether or not there are strong pure-tone components; the temporal pattern of the noise, including the rate of repetition and the actual time of occurrence during the day; and the general level of noise in the residential community affected.

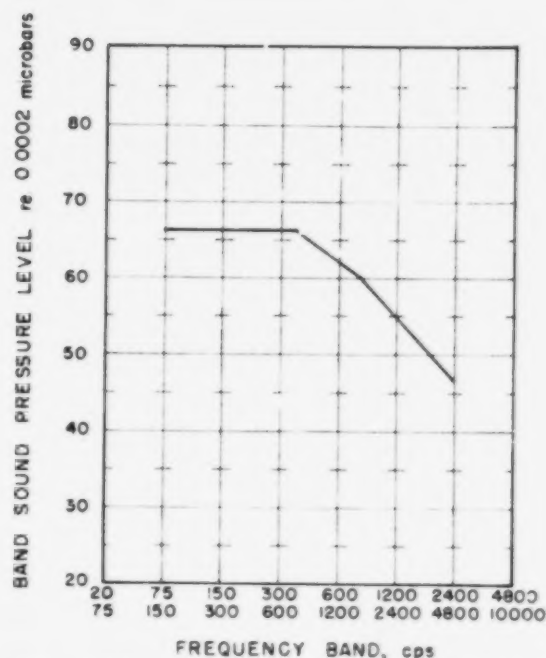


Figure 13. - Federal Housing Administration's recommended impact noise curve for floor/ceiling constructions (T.J. Schultz).⁽³⁰⁾

A. Noise Rating - Level Rank

A tentative method of rating noise in the residential areas has been proposed by W.A. Rosenblith and K.N. Stevens.⁽³³⁾ This system of rating is applied in the following manner: The levels of noise in octave-bands are measured in the neighborhood under different circumstances. Depending on the types and sources of noise, and the weather conditions, measurements of noise may require surveys over long periods of time. These measurements, when plotted on a chart similar to that shown in Figure 14, establish a "level rank" for the noise. This rank is then corrected by the numbers in Table VIII, according to the factors listed. In addition, a correction is made for background noise, using Figure 15. The net correction results in a shift in rank upward or downward. By using the curves shown in Figure 16, which are based on the corrected rank, the community reaction to noise can be predicted.

For example, assume that the octave-band levels produced at night by a newly erected power substation, at the nearest house in a suburban area, are as follows:

Octave-Band - cps	20 - 75	75 - 150	150 - 300	300 - 600	600 - 1200	1200 - 2400	2400 - 4800	4800 - 9600
Power Station Band Level -dB	30	48	47	38	34	28	22	22
Back ground -dB	40	41	35	30	25	20	14	10

When the levels of the octave bands of the power station are plotted on Figure 14, it can be seen that the rank of the

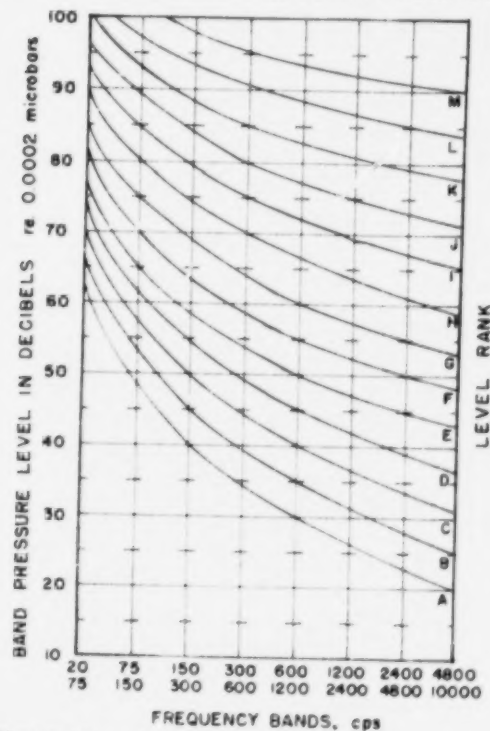


Figure 14. - Set of curves for assigning a rank to a residential noise. The levels of octave-bands of the noise are plotted on this chart. The highest of the alphabetically labeled zones into which any band level penetrates is the ranking of the noise (W.A. Rosenblith and K.N. Stevens). (32, 33)

band at 150-300 cps is the highest, yielding a rank of "C". This rank is then corrected by the numbers in Table V, according to the factors listed. For the assumed noise, the spectrum has a strong pure tone component (+1); it is a steady noise (0), not impulsive (0), in a suburban neighborhood (0), at night-time as well as daytime (0); and the correction for background determined by plotting the background octave-band levels on Figure 15 is (-1). The net

correction is then a shift upward to a corrected "level rank" or noise rating of "E". Then from Figure 16, it can be

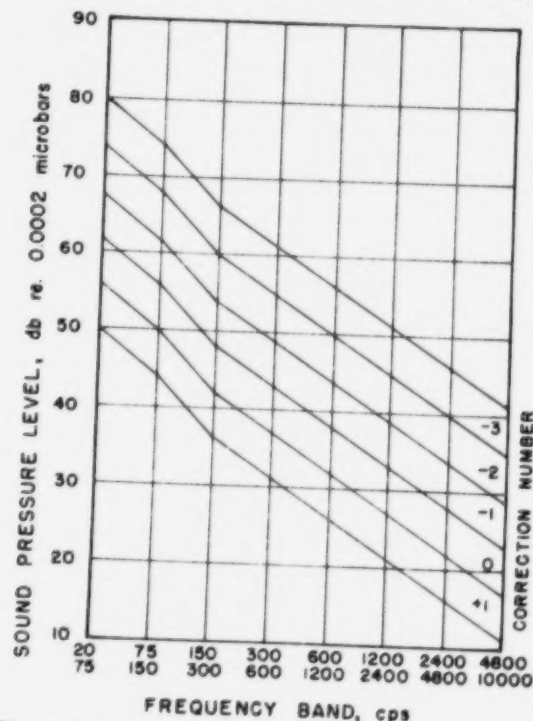


Figure 15. - Correction for background noise to be applied to the rank determined from Figure 14. The highest zone into which any of the band levels penetrate is the correction to be applied to the level rank (W.A. Rosenblith and K.N. Stevens) (32, 33)

predicted that there will probably be widespread complaints about the noise. The power company should try to reduce the noise level in order to avoid losing the goodwill of the neighborhood.

This system of rating can be used also in the opposite direction. Thus, the sort of response which could be risked

is determined, and from that information the maximum allowable levels in each octave-band can be ascertained.

The "level rank" procedure is presented

only as a guide. As more experience is obtained with the problems of neighborhood noise, it can be expected that some revision of the numerical values will be found desirable.

Table VIII
Correction Numbers to be Applied to
Rank to Yield Ratings of Noise

Influencing Factor	Possible Conditions	Correction Numbers
Character of Spectrum	Pure tone components	+1
	Wide-band noise	0
Peak Factor	Impulse	+1
	Non-impulse	0
Repetitive Character	Continuous exposure to one per minute	0
	10-60 periods of exposure per hour	-1
	1-10 periods of exposure per hour	-2
	4-20 periods of exposure per hour	-3
	1-4 periods of exposure per hour	-4
	1 exposure per day	-5
Time of Day	Nighttime	0
	Daytime only	-1
Adjustment to Exposure	No previous conditioning	0
	Considerable previous conditioning	-1
	Extreme conditioning	-2

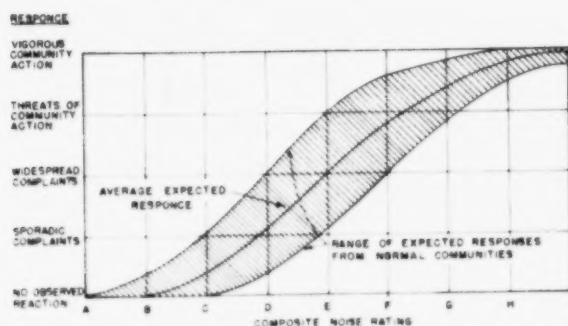


Figure 16. - Relation between the noise rating determined from Figure 14, Figure 15, and Table VII and the expected response from the residents exposed to noise (W.R. Rosenblith and K.N. Stevens). (32,33)

B. The Level of Noise as Perceived (Units - PNdB)

The Perceived Noise Level (PNL), that is, the degree of perception of a particular sound or noise, expressed in decibels (PNdB), is defined as the sound pressure level of a band of noise from 910 to 1,090 cps that sounds as "noisy" as the sound or noise under comparison. The principal difference between loudness level and that of perceived noise level is that "equal-annoyance contours," instead of "equal-loudness contours," are used in their derivation.

For a number of years investigators have been trying to devise a single number which would correlate with the annoyance potential of a particular noise. D.A. Laird and K. Cozi, in 1929, (34) and T.W. Reese and K.D. Kryter, in 1944, (35) reported on some of the earlier work. A proposed method of computing perceived noise level was presented by K.D. Kryter in 1959, (36) and refinements of the method were presented in a paper published in 1963. (37) The development and use of the PNdB has been limited primarily to the aircraft industry, in which it has been used to rate the "annoyance potential" of various aircraft. The PNL is being used as

a limit for the levels of noise produced by aircraft in landing and taking off at certain airports, such as the limit of 112 PNdB set by the Port of New York Authority for airport operations under their jurisdiction. Evaluations of the PNdB are being made to predict the annoyance potential of other noises. One such attempt is presented in a report prepared by the Division of Occupational Health on the comparison of noise produced by aircraft, automobiles, and trains, and on their ratings of annoyance. (38)

The United States Air Force has developed a guide for noise associated with aircraft, in communities adjacent to military air bases. This guide is discussed in detail in a report by A.C. Pietrasanto and K. N. Stevens. (39) The Air Force developed another guide in 1964 to assist in planning for the utilization of land in the vicinity of military, civil, and combined airfield facilities. (40) This guide uses the number of predicted operations for each type of aircraft, and the distribution of these operations over the period of 24 hours, to predict the level of annoyance around an airport. This is a detailed guide giving a step-by-step procedure for planning the usage of land in the vicinity of the airport so as to minimize complaints as to noise.

Criteria for Audiometric Rooms

Audiometric rooms are the only areas for which definite maximum allowable sound pressure levels are available and acceptable to all investigators. These are given in the American Standards Association S3.1-26 Standard, the American Standard Criteria for Background Noise in Audiometric Rooms, of the American Standards Association. The levels are shown in Table IX.

Because of the difficulty in many cases in reducing the levels of noise to the recommended levels, attempts have been made to design new head phones for audiometric tests, including the use of earmuffs. (41)

Table IX

Maximum Allowable Sound Pressure Levels for No Masking
Above the Zero Hearing Loss Setting of a Standard Audiometer

(Decibels re 0.0002 Microbar)

Audiometric test frequency (cps)	125	250	500	750	1000	1500	2000	3000	4000	6000	8000
1/3 octave band center frequency (cps)	125	250	500	800	1000	1600	2000	3200	4000	6400	8000
Sound pressure level (dB)	35	35	35	35	35	37	42	47	52	57	62
1/2 octave band cut-off frequency (cps)	106 - 150	212 - 300	425 - 600	600 - 850	850 - 1200	1200 - 1700	1700 - 2400	2400 - 3400	3400 - 4800	4800 - 6800	6800 - 9600
Sound pressure level (dB)	37	37	37	37	37	39	44	49	54	59	64
Octave band cut- off frequency (cps)	75 - 150	150 - 300	300 - 600	600 - 1200	600 - 1200	1200 - 2400	1200 - 2400	2400 - 4800	2400 - 4800	4800 - 10,000	4800 - 10,000
Sound pressure level (dB)	40	40	40	40	40	42	47	52	57	62	67

Some of these special headsets, however, which are being sold currently, do not attenuate the noise to the extent claimed in advertising material. In addition, their use may cause erroneous readings in audiometric determinations at certain frequencies.

Conclusions

A survey of the literature has been made in search of criteria for the appraisal of noise in various situations. Definite and universally acceptable limits are available for only a few situations, but guidelines have been proposed for the solution of the majority of the problems concerned with noise that will be encountered in the industrial and general environment.

It is believed that all except highly susceptible individuals will be protected from loss of hearing when subjected to noise continuously, for 8 hours per day, if the levels are maintained below the limits shown in Table X. For each increase of 3dB above these limits, the length of the periods of exposure should be cut by one-half. No criteria are available for safety in relation to impact noise. The best assurance against excessive exposure to noise is provided by the regular, periodic resort to skilled, monitoring audiometry in determining that there is no change in hearing acuity of the exposed group.

Recommended maximum levels of noise for the prevention of complaints of excessive noise in typical areas within buildings are shown in Table X. Recommended levels for other areas are shown in Tables VI and VII and in Figures 9 and 10. If the levels of noise are maintained below that represented in the appropriate curve for a particular

type of room, it should be possible to eliminate complaints.

Very little guidance for the required degree of insulation against sound in buildings in the United States is available in national or local building codes. Such requirements are included in the building codes of many European countries, and these can serve as guides until codes have been developed in the United States. The requirements set by British building codes, and the recommendations of the Federal Housing Administration are shown in Table IX.

Guidelines are available for the prediction of community reaction to noise, and it is believed that the majority of the problems concerned with noise in the community, can be evaluated by using the methods proposed by Rosenblith and Stevens. Two typical levels are shown in Table X. For a true evaluation, many community variables must be considered and necessary corrections must be applied to the measurements of noise. For the special problems of airports, Manual 86-5, "Land Use Planning with Respect to Aircraft Noise," prepared by the U.S. Air Force, should be helpful. This publication gives a step-by-step procedure for analyzing this problem in relation to types of aircraft, volume of traffic, and many other factors.

The American Standards Association in S3.1.26 Standard, the American Standard Criteria for Background Noise in Audiometric Rooms, provides definite limits for audiometric test facilities.

These standards, if used judiciously, should enable the industrial hygienist to deal satisfactorily with the majority of the problems posed by noise.

Table X
Summary of Standards for Evaluation of Noise in Various Situations

Sound pressure levels in octave-bands
re 0.0002 dynes/cm²

Area	Type of Criteria	20-75	75-150	150-300	300-600	600-1200	1200-2400	2400-4800	4800-9600	Remarks
Industry	Hearing loss-continuous broad-band	103	98	92	89	85	85	85	85	Many years, 8 hours per day
	Hearing loss-continuous narrow-band	93	93	87	84	80	80	80	80	Many years, 8 hours per day
	Hearing loss-impacts	--	--	--	--	--	--	--	--	Insufficient information for criteria
Buildings	Annoyance Executive offices	57	47	38	32	28	25	23	22	For other types of areas consult Tables V & VI & Figures 9 & 10
	Annoyance Hospitals	60	51	43	37	33	20	28	27	
	Annoyance Drafting rooms	73	69	64	59	57	55	53	52	
Buildings	Sound insulation British code	--	35	40	45	50	55	--	--	Minimum insulation
	Impact British Code	--	63	65	65	63	58	52	--	Minimum reduction
	Impact U.S. FHA recommendation	--	66	66	66	62	55	47	--	Minimum reduction

Table X (continued)
Summary of Standards for Evaluation of Noise in Various Situations

Sound pressure levels in octave bands re 0.0002 dynes/cm ²											
A Area	Type of Criteria	20- 75	75- 150	150- 300	300 - 600	600- 1200	1200- 2400	2400- 4800	4800- 9600	Remarks	
Community	Annoyance residential Few complaints	70	57	49	44	40	36	33	31	Consult Figures 15 and 16 and Table VII for corrections for community variables	
	Annoyance residential Widespread complaints	78	66	58	54	50	46	44	42		
Audio- metric Rooms	ASA S3.1, 26 Standard	--	40	40	40	40	42	52	62	Maximum level for measuring zero hearing loss	

NOTE: These values shown in this Table are based on the best information available but are not to be interpreted as Public Health Service standards.

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EQUIPMENT FOR MEASURING NOISE

Introduction

The industrial hygienist is being called on more frequently to make noise measurements and evaluate noise problems. These may be problems of potential hearing loss of employees due to excessive noise exposures, annoyance from a noise in a building or community, compliance with noise specifications, or requirements for a low noise background for audiometric testing. In any of these situations the industrial hygienist will need to determine (1) total sound pressure level, (2) distribution of this sound pressure or energy with frequency and (3) distribution of this sound pressure or energy with time. The type of noise source will dictate which equipment is necessary in order to make an accurate evaluation of these three factors.

Types of Equipment

At the present time there is a wide assortment of equipment available for noise measurements. The choice of equipment used will depend on the type of noise encountered and the purpose of the measurements. Specific types of equipment will be discussed, including the general features of each type. In most cases commercially available instruments will incorporate all of these features. It has been the author's experience that manufacturers may modify equipment electronically, which results in changes in operating procedures even though the exterior appearance of the instrument remains unchanged. Therefore, it is essential that the instruction book, which was obtained with the instrument be consulted freely.

Prepared by: Herbert H. Jones

Sound Survey Meter

The sound survey meter is a small instrument that usually consists of a non-directional microphone, an adjustable calibrated attenuator, an amplifier with three weighting networks, and an indicating meter.

The instrument has a function switch with an off position, A, B, and C weighting network positions, and a battery check position. It has either a continuously variable or stepped attenuator. The sound pressure level is the sum of the attenuator setting and the reading from the indicating meter.

Even though the sound survey meter does not meet American Standards Association specifications for sound level meters, it is a good instrument for rapid screening and surveying of a large area or number of locations.

Sound Level Meter

The sound level meter is the basic instrument used for noise measurements. It comprises a microphone and an electronic circuit including an attenuator, an amplifier, three frequency response networks (weighting networks), and an indicating meter. The attenuator in the circuit controls the current within limits that can be handled by the indicating meter, which is calibrated in decibels. The value obtained is the root-mean-square sound-pressure level expressed in decibels re 0.0002 dynes per sq. cm.

Sound level meters are available in the range of 20 to 180 decibels (dB) (re 0.0002 dynes/sq.cm.). The newer sound level meters provide an amplifier with a flat frequency response from 20 to 20,000 cycles per second (cps), and the overall response depends on the microphone used. The design criteria for sound level meters (American Standards Association, 24.3 -1944 and S1.4 -1961)

permit large tolerances at both low and high frequencies. This emphasizes the need for the proper calibration of each instrument.

Three weighting networks, A, B, and C are included. The purpose of these is to give a number which is an approximate evaluation of the total loudness level. Human response to sound varies with its frequency and intensity. The ear is less sensitive to the low and high frequencies at low sound intensities. On the other hand, at high sound levels there is less difference in human response at the various frequencies. The three weighting networks provide a means of compensating for these variations in human response.

The A network is less sensitive to low frequencies and is intended for use at sound pressure levels below 55 dB. The B network is an intermediate step for the range of from 55 to 85 dB. The C network has a flat response and is used for everything above 85 dB. The C network is the only one which indicates the actual sound pressure level, since the sound pressure level is based on a flat response.

Microphones

The microphone is by far the most important part of the equipment, since the quality of the final result can be no better than the signal produced by the microphone. The function of the microphone is to respond to the sound energy and convert it to electrical energy, which is fed to the electronic circuit.

The frequency response, sensitivity, directionality, and range of a sound level meter are primarily determined by the microphone; therefore, its importance cannot be overemphasized.

Three major types of microphones are in general use for the measurement of sound. Each type has advantages and disadvantages, and the final selection depends on the requirements of the job to be done.

Rochelle Salt Crystal Microphone. A Rochelle salt crystal microphone was supplied as standard equipment on sound level meters for many years. The reasons for this were its low cost, ruggedness, availability, and high sensitivity. It has a frequency range of 20 to 8000 cps and an intensity range of 24 to 150 dB. Its frequency response varies widely with the incidence of the sound and the response is far from flat above 2000 cps.

One of the disadvantages of the Rochelle salt microphone is its sensitivity to heat and humidity. Temperatures above 115°F may damage the crystal and temperatures above 125°F will destroy it. Also, there is a reversible change in sensitivity produced by temperature change. When an extension cable is used and the input impedance of the meter is high, a temperature correction is necessary.

Ceramic Crystal Microphone. Since 1963 a PZT (lead titanate-lead zirconate) piezo-electric - ceramic diaphragm type microphone has been regularly supplied with many of the sound level meters. This is a stable and rugged microphone with a smooth frequency response and it is relatively unaffected by normal temperature and humidity changes. It has a frequency range of 20 to 9000 cps and an intensity range of 24 to 150 dB. It will withstand temperatures of 22 to 205°F without damage. A correction is necessary when the PZT microphone is used with an extension cable. A correction of about 7 dB is made when a 25 foot cable is used between the microphone and the instrument.

Dynamic Microphone. This is probably the second most commonly used type. It operates on the principle of a coil moving in a magnetic field, resulting in an induced voltage. This type of microphone has a dynamic range of 20 to 140 dB and a frequency response in the range 40 to 10,000 cps of ± 5 dB. Its frequency response is less erratic than the crystal microphone, but the frequency response drops off sharply below 40 cps.

The dynamic microphone has the advantage of low self-noise, permitting noise measurements down to less than 20 dB in an octave band. Sensitivity to temperature change is small up to 180°F, and it can be used with long extension cables without correction. This microphone cannot be used in strong magnetic fields such as those encountered around large transformers, generators, or electric arc welders. Care must be taken to avoid getting the microphone wet because of the possibility of internal shorts.

Condenser Microphone. This is the least commonly used of the four microphones. It consists of two plates which act as a condenser; one is a thin diaphragm, the other a solid backing. Movement of the diaphragm changes the capacitance of the condenser in proportion to the displacement of the diaphragm. This change in capacitance produces an electrical signal that is proportional to the sound pressure level.

This microphone has the best frequency response of all types in current use. It is available in models which are essentially flat in response to frequencies from 20 to 8,000 and ± 3 dB at 15,000 cps to models which are essentially flat from 20 to 200,000 cps. The dynamic range is from 40 to 145 dB in the standard models with special models available with an upper limit of 200 dB. Its temperature sensitivity corresponds to that of a dynamic microphone. It can be used at higher temperatures and with a cathode follower it can be used with long cables without corrections.

Disadvantages are its high cost, high self-noise, limited humidity range, and additional electronic complexity due to the preamplifier which is required. High humidities may increase internal noise but this can be corrected by keeping the microphone in a desiccator when not in use.

Noise Analyzers

When the sound to be measured is complex, consisting of a number of tones, or having a continuous spectrum, the single value obtained from a sound level meter reading often is not sufficient for evaluating the effects of noise. It may be necessary to determine the sound pressure distribution according to frequency.

In general, there are three types of noise analyzers:

- (1) octave, half octave, and third octave bandwidth,
- (2) constant bandwidths, and
- (3) constant percentage narrow band.

Octave band analyzer. The most practical and widely used analyzer for industrial noise studies is the octave band analyzer. As indicated by the name, the upper cutoff frequency is twice the lower cutoff frequency. For a half-octave analyzer the upper cutoff frequency is $\sqrt{2}$ times the lower, and for a third-octave analyzer the ratio is $3\sqrt{2}$. A commonly used set of octave pass bands in commercial equipment is 20 to 75, 75 to 120, 150 to 300, 300 to 600, 600 to 1200, 1200 to 2400, 2400 to 4800, and in excess of 4800 cycles. This analyzer provides sufficient data on industrial noise to evaluate its physiologic significance and to provide a basis for noise control. The small number of bands makes it possible to perform an analysis in a reasonable length of time, and the bands are wide enough to reduce the problem of transient components affecting stability of the meter.

This analyzer may be equipped with one of two types of filters. In one type there is a choice of eight pass-bands and the selection is made by a single switch. The second type consists of a low cutoff filter, which filters out all frequencies below the setting of the dial; and a high cutoff filter, which filters out all frequencies above the setting of this dial. Measurements can

be made in bands of one octave or multiples of an octave to cover the complete spectrum using the second type of analyzer. The attenuator, which is 50 dB in 10 dB steps, and the amplifier serve the same purpose as in the sound level meter. The meter has a 16 dB range. The sound pressure level within the chosen band is the sum of the sound level meter attenuator setting, the analyzer setting, and the analyzer meter reading. The analyzer has a rheostat for adjusting the indicator to correspond to the meter reading on the sound level instrument when the analyzer is set to the overall position.

All octave band analyzers are equipped with an output jack permitting the use of headphones, a recorder, or an oscilloscope.

At the present time some octave band analyzers use the American Standards Association's preferred frequencies. In these analyzers the octave bands are centered around the following mid-frequencies: 63, 125, 250, 500, 1000, 2000, 4000, and 8000 cycles per second. Although there is a shift in octave bands utilized on the standard analyzers, there is no practical difference in the interpretation of data for industrial hygiene significance.

Constant bandwidth. This instrument has a fixed bandwidth that is a specific number of cycles wide. Common bandwidths range between 5 and 200 cps. These are essentially laboratory instruments requiring line voltage for operation. Because of the transient nature of industrial noise and the narrow bandwidth of the analyzer, this instrument is seldom used in industrial noise studies.

Constant-percentage bandwidth. The constant-percentage narrow band analyzer has a bandwidth which is a fixed percentage of the mid-band frequency. Thus, at low frequencies the bandwidth will be only a few cycles, while at high

frequencies the bandwidth will cover a wide range of frequencies. This instrument has essentially the same limitations as the constant bandwidth analyzer but it can be used in some noise control problems.

Accessories

A number of accessories are available for use with sound level meters and frequency analyzers to give additional information about the noise situation under study.

Impact noise analyzer. This instrument operates directly from the output of the sound level meter or frequency analyzer. It can be used to measure the peak level and duration of impact noise.

Through the use of electrical storage systems, three characteristics are measured by the analyzer for every impact noise. These are the maximum instantaneous level, the average level, and a continuously indicating measure of peak sound levels. The values can be read individually on the same meter by means of a selector switch. A reset position of the selector switch restores the meter to its pre-reading condition.

Cathode-ray oscillograph. An oscillograph affords a useful means for observing the wave form of a noise and also for observing many general noise patterns, particularly short duration or impact noises. The oscillograph can be operated from the output signal of a sound level meter, octave band analyzer, or magnetic tape recorder. It can be used to measure the peak amplitude, the rate of decay, and the shape of a wave.

A cathode-ray oscillograph with a sweep rate extending down to at least two seconds and a long persistence screen is preferable for acoustic measurements. If the wave form is to be photographed, a short persistence screen should be used. A five-inch oscillograph tube is normally used for this latter purpose.

The output of the sound level meter, sound analyzer or magnetic tape recorder are connected to the vertical input of the oscillograph. The controls are set as explained in the instruction manual for the oscillograph. A reference signal of 60 cps, or 400 cps can be fed into the sound level meter to adjust the gain of the vertical amplifier. The reading on the meter is noted and the vertical gain is adjusted to obtain a peak-to-peak deflection according to the table below for a five-inch screen.

Meter Reading dB	Peak-to-Peak Deflection inches
0	1.00
1	1.12
2	1.26
3	1.41
4	1.59
5	1.78
6	2.00
7	2.24
8	2.51
9	2.82
10	3.16

Once set, the gain control of the oscillograph should not be changed, adjustments being made with the attenuator on the sound level meter to keep the maximum deflection within the range of the table above.

The peak-to-peak sound pressure level for a noise is the decibel value obtained from the table above plus the sound level meter attenuator setting plus 9 dB.

Magnetic tape recorder. The magnetic tape recorder can be used for recording noise in the field with subsequent analysis in the laboratory. Detailed and repeated studies can be made or the tape can be kept for later analysis or comparison purposes.

If meaningful measurements are to be made from a recording, a high quality recorder must be used. It should have a flat frequency characteristic over a

wide range, low hum and low noise level, low nonlinear distortion, and a constant speed drive; also it should be of good mechanical construction. A tape speed of 15 inches per second is recommended, since the above characteristics are more readily obtained and maintained at high tape speeds.

The gain control should be set according to instructions supplied with the recorder. After it is set a reference signal should be recorded, such as the signal from an acoustical calibrator. Whenever the gain control is reset, a reference signal should again be recorded.

When an analysis is desired a representative sample should be selected and that portion of the tape is spliced to form a loop so it can be repeated continuously. If the absolute level needs to be known, a sample of the recorded reference signal should be measured with the same control settings as were used for the sample.

It might appear that the only instrument needed in the field would be a good tape recorder; but in many situations it will be better to make the analysis in the field with the usual sound equipment to make certain that all of the desired data have been obtained.

Graphic level recorder. The graphic level recorder provides a permanent record of the noise characteristics by tracing a graph on a moving paper. The recorder can be operated from the output of the sound level meter or the octave band analyzer to record the level of a noise as a function of time. It is subject to the same limitations as the sound level meter in the analysis of noise of short duration.

When using the graphic level recorder it must be calibrated with an acoustical calibrator. The gain control should be adjusted according to instructions supplied by the manufacturer.

Acoustic Calibrator

An overall acoustic check can be made of the sensitivity of a sound level meter including its microphone by the use of an acoustic calibrator. Calibration may be accomplished with either electronic or mechanical devices. The electronic calibrator consists of a small speaker mounted in an enclosure which fits over the microphone of the sound level meter. The enclosure is designed in such a way that the measurements can be repeated with a high degree of accuracy. Signals may be supplied to the calibrator from either an audio oscillator or random noise generator depending on which calibrator is being used. The designated operating voltage of the supplied signal and the sound level output can be found in the operating instructions furnished by the manufacturer when the calibrator is purchased.

Two types of mechanical acoustic calibrators are available commercially. One is a piston activated diaphragm mounted in an enclosure, which is placed over the microphone. The other type

consists of a diaphragm, which is activated by steel balls dropping onto it. This calibrator is placed at a specified distance from the microphone to be calibrated. Each type of calibrator, when operated according to the manufacturer's instruction, will produce sound of a specified level.

Dosimeters

Three different types of noise dosimeters are available at the present time. These are designed to indicate in some manner the total noise dose during a specified time interval. Each of these instruments uses a different approach; one type measures the total amount of sound energy to which a worker is exposed for a workday, another type measures the amount of time that a specified decibel level is exceeded, and the third measures the rate at which sound energy impinges on the exposed person for selected short-term periods of time. Correlation of these dosimeter readings with hearing loss is lacking. Such data cannot be used at the present time to evaluate damage risk to hearing from variable exposure situations.

THE NOISE SURVEY

Introduction

The noise survey is the practical application of a number of noise measurements and observations to evaluate a noise situation. Proper evaluation of a noise problem depends upon accurate and meaningful measurements. Even though the equipment is electronic and may appear to be simple to operate, one should use it with caution and be on the alert to detect errors due to the operation of the equipment or the influence of the environment.

There are a number of reasons for conducting noise surveys; among these are:

1. To evaluate the risk to noise-induced hearing loss. Sufficient information is available at the present time to classify certain noise situations in terms of the probable noise-induced hearing loss which may occur among workers exposed for given periods of time. To evaluate this problem it would be necessary to determine the intensity, distribution of intensity, and frequency and duration of exposure. These three factors indicate whether or not a risk of noise-induced loss exists and, if so, to what extent.
2. To determine adherence to noise criteria. In some situations it is necessary to evaluate the noise environment with regard to pre-established guides, codes, regulations, laws, or other governing noise criteria. Ideally, the imposed noise criteria will agree with valid damage risk criteria or standards for evaluating the risk of noise-induced hearing loss.
3. To provide information for determining the need of engineering and other methods of control. Certain noise situations will indicate the need for implementing various forms of engineering control. The sound pressure level measurements will determine the amount of control necessary to reduce the noise to an acceptable level. This may require special measurements to locate sources of noise and provide information on a procedure for noise reduction.
4. To evaluate engineering control measures. To validate the effectiveness of engineering control, a survey should be conducted subsequent to the implementation of the control. Periodic surveys will indicate if existing controls are operating effectively and efficiently.
5. To evaluate complaints of annoyance, speech interference, safety hazards, etc. Guidelines are available for evaluating annoyance levels for community noises, noise levels in occupied spaces, and speech interference. These guidelines are discussed in Section N-5.
6. To contribute to research. Present noise criteria and engineering control techniques have been determined, in part, as a result of noise survey data made available to interested groups. It is hoped survey data will become available for the purpose of better understanding the total effects of noise.

General Considerations

On most occasions the reason for conducting an industrial noise survey will dictate the type of survey one should perform. The type of survey may also be

Prepared by: Herbert H. Jones

influenced by the type of equipment available, the availability of technically trained personnel, and the time available for the survey. An industrial health group with responsibilities for an effective program should have the following minimum equipment:

Sound Level Meter
Octave Band Analyzer
Acoustical Calibrator
Microphone Extension Cables

Operation of Instruments

The sound level meter has an on-off switch, a means of checking battery voltages, a selector for one of the three weighting networks, a fast-slow meter response switch, an attenuator with steps of 10 dB, and an indicating meter (16 dB range). The instrument is turned on; batteries are checked; the instrument is permitted to warm up for a few minutes; and the attenuator is adjusted until the indicating meter is on scale. The sound pressure level is the algebraic sum of the attenuator setting plus the meter reading.

The octave band analyzer operates from the output of the sound level meter and may be a separate instrument or may be combined in the same case with the sound level meter. The analyzer has an on-off switch, battery voltage check, a fast-slow meter response switch, an attenuator, and cut-off filter or filters permitting the selection of the octave bands to be measured. If they are separate instruments, the analyzer and the sound level meter must be connected by a cable. Both instruments are turned on, and the batteries checked. The frequency analyzer band selector is set at 20 to 20,000 cps and the two meter readings should agree. The overall sound pressure level is recorded; then the band selector is changed to include only the lowest octave band (20 to 75 cps), and the attenuator on the analyzer adjusted until the indicating meter is on scale. The sound pressure level obtained in this octave band is the sum,

observing the appropriate signs, of the attenuator setting of the sound level meter, the attenuator setting of the octave band analyzer, and the octave band analyzer indicating meter. This is repeated for each of the octave bands; then the overall sound pressure level should be measured again to assure that there has been no appreciable change in frequency or intensity of the noise during the analysis.

Maintenance of Equipment

The equipment normally used is battery powered electronic equipment, and one should constantly be on the lookout for faulty operation. The equipment should be checked before it is taken from the laboratory because of the availability of a quiet location and test instruments if repair is necessary. The following steps should be taken:

1. Connect and turn on the instruments; allow them to warm up for a few minutes.
2. Check batteries.
3. Make acoustical calibrations.
4. Make octave band measurements of a convenient wide band steady noise.
5. Remove the microphone and make electrical background measurements.
6. Recheck acoustical calibration.

If any of the above steps indicate a malfunction of the equipment, the instruction manual supplied with the instrument should be consulted for necessary adjustments or repairs. If the first three steps are completed satisfactorily, this usually means that the equipment is operating properly. Step 4 can expose a defective octave band cut off filter which might be overlooked in making measurements in the field. Step 5 will indicate a faulty tube or oscillating amplifiers. Step 6 could indicate weak batteries if the calibration has changed by more than 1 dB. If it has changed, the batteries should be replaced before making measurements.

Precautions for Handling Equipment

Since electronic equipment can be damaged by shock, extreme care must be taken in transporting the equipment. When equipment is to be transported by commercial carrier, extreme care must be taken in packing the equipment, providing a minimum of two inches of good packing material on all sides of the instruments.

Many sound level meters in use today are equipped with a Rochelle salt crystal microphone which can be damaged by excessive heat. The microphone should not be subjected to temperatures above 115°F for any appreciable length of time; it should never be left in the trunk or inside a closed automobile on a hot summer day.

Calibration of Equipment in the Field

When the area is reached where measurements are to be made, all of the steps, except Step 4, listed under Maintenance of Equipment should be repeated, preferably before the equipment is taken into a noisy area. The acoustical calibration should be performed in an area where the background noise, with the calibrator in place, is 10 dB less than the calibration signal.

The acoustical calibrator can be used also to determine the temperature and/or cable correction needed for an extension cable between the microphone and the sound level meter. The readings should be obtained both with and without an extension cable between the microphone and the sound level meter. The difference is the correction to be added to the readings obtained when the cable is in use. This correction is a function of ambient temperature of the microphone, not a function of frequency; and these readings should be collected after the microphone temperature is in equilibrium with the room temperature at the location of the survey. All data should be collected after the microphone temperature has reached the

room temperature where the measurements are to be made. This correction can also be made by inserting the cable and adjusting the calibration to give the proper reading.

If a large number of measurements are made at one time, the batteries should be checked periodically and the equipment calibrated a minimum of four times a day.

Types of Surveys

In general, there are three types of noise studies. The simplest of the three is a screening survey which can be made with a sound survey meter or sound level meter. This type survey may involve making a number of measurements of overall sound pressure level in an area for rapid evaluation of the problem and determining if a more detailed study is needed.

The second is the general noise survey to determine the characteristics and potential effects of a noise. This involves the use of a sound level meter and a frequency analyzer in order to determine distribution of the sound pressure level with frequency. For industrial hygiene activities an octave band analyzer would probably be used to evaluate the distribution at various frequencies.

The third type of survey is for research, noise control, or other special purposes. Not all noise problems can be surveyed directly with the sound level meter and octave band analyzer. An abrupt peak noise such as that made by a punch press cannot be accurately measured because of the slow response of the sound level meter. Therefore, an impact noise analyzer is attached to the sound level meter to record the peak noise levels. A cathode ray oscilloscope and magnetic tape recorder may also be used for this purpose, but they are bulky and cumbersome to operate; therefore, the impact analyzer is usually the instrument of choice. These surveys may require

a large number of measurements and analyses in the field; also magnetic tape recordings may be made for later analysis in the laboratory. A sufficient number of samples should be taken to determine the exact nature of the source power and the directionality of the noise.

Types of Noise

It is essential to define the types of noise to be measured in a survey as this may determine the equipment necessary for accurate measurements. Noise may be classified according to type as follows: steady wide-band, steady narrow-band and impulse. Any of these could be intermittent or cyclic in nature.

1. Steady wide-band noise. This is defined as noise in which the energy is spread over a wide range of frequencies and is continuously emitted over an extended period of time. An example of this is the noise generated in weave rooms in textile mills, in piston type aircraft, and in air moving through a duct. Screening and octave band measurements can be made with very little difficulty.
2. Steady narrow-band noise. In this type there is a concentration of the noise energy in a narrow frequency range. Examples include noise produced by circular saws, generators, sirens, and compressors. To evaluate these noise problems it is necessary to use an octave band analyzer or, possibly, an analyzer with band widths of less than one octave.
3. Impulse noise. This noise is characterized by its short-time duration created, for example, by explosions or drop hammers. The peak sound pressure level can be as much as 20 to 30 decibels higher than the reading on a sound level meter. This is due to the reaction time of the instru-

ment, which is not fast enough, even on the fast response scale, for the meter to reach a peak value before the noise ceases. Measurements of this type are made with an impact meter, which gives not only the peak sound pressure level, but also the delay time of the impulse. Repeated impulse noises, such as those produced by riveting and pneumatic hammers are more complicated. Repeated impulse noise up to approximately 50 impulses per minute can be measured with the impact meter. Impulses above 200 per minute are best measured with the sound level meter and octave band analyzer because such rapid impulses approach the characteristics of a continuous noise. In the range of 50 to 200 impulses per minute, readings must be evaluated in the light of experience.

Sources of Error

The reliability of noise measurements depends upon the manner in which the instruments are used and their operating condition. The immediate recognition of faulty equipment is essential if accuracy is to be maintained.

The area in which the noise survey is to be made should be investigated to determine what measurements would be representative. The possible effects of obstacles on the distribution of sound, particularly at high frequencies, should be kept in mind during this preliminary exploration.

The microphone should be located at the side of the operator or observer and not between the noise source and the operator or observer. When measurements are made near a single noise source, large errors may result; however, in a large room with a number of sources of noise, if measurements are made at some distance from the source, only small errors would be expected.

Wind can produce appreciable interference at low frequencies. If it is necessary to sample in the wind, a wind screen should be used. These can be purchased or can be fabricated out of hardware cloth with a covering of fine cloth.

All vacuum tubes are affected by mechanical vibration. The tubes used in sound measuring equipment have been selected to be less sensitive to shock than most vacuum tubes. At high noise levels vibration may be to such an extent as to produce extraneous noises in the vacuum tubes which will effect the readings obtained with the equipment.

In very intense noise fields it may be necessary to remove the meter from the area and use an extension cable to the microphone. Vibration may also be transmitted to the equipment when it is placed on a vibrating source or in a vibrating field. A test for the effect of vibration is to disconnect the microphone from the sound level meter and observe if a reading is obtained on the meter. If a reading is noted, the meter can be placed on a rubber pad or rubber tired cart, or mounted in such a manner as to eliminate the vibration of the equipment.

When making noise measurements around electrical equipment there may be appreciable pickup of the electromagnetic field by the instruments. This may be an important error when using a dynamic microphone. A pair of good quality earphones can be used to monitor the output of the sound level meter or octave band analyzer. The hum produced by the electromagnetic field will be of the same frequency as the power source, usually 60 cycles per second. The orientation of the instruments and microphone should be changed to determine if there is a difference in the meter reading; also, the microphone should be disconnected to check if the interference is in the microphone or the instruments. If the interference is in the instruments they should be re-

moved from the area of the electromagnetic field and an extension cable used, a crystal or condenser microphone may also have to be substituted for the dynamic microphone under these conditions.

When making noise measurements at low intensity levels the inherent circuit noise may be the limiting factor. The lower intensity limit of measurement may be determined by removing the microphone and substituting a capacitor of the proper size.

The Screening Survey

Purpose

The major purpose of the screening survey is to obtain information in a relatively short period of time which will enable one to decide if a more detailed survey is required. The screening survey can give information concerning the characteristic of the noise; whether it is broad-band, narrow-band, impulse, continuous, intermittent or cyclic, as in all surveys, the screening survey is more than just a compilation of noise measurements. While conducting a survey of this type one can make significant observations concerning the worker and his relationship to the noise environment, the types of noise control being used, and the general attitude of the plant population concerning their exposure to noise.

Equipment

The screening survey requires less equipment than is necessary for the other surveys; all that is actually required is a sound survey meter or sound level meter. The sound level meter may provide more accurate measurements than the survey meter but the greater accuracy is not necessary for the screening survey. The advantages of the sound survey meter are its low cost and its high degree of portability due to its small size. The small size of this instrument is most convenient in conducting a screening survey since it is

possible to carry this compact instrument around while making other types of industrial hygiene surveys and taking notes concerning the need for more detailed types of noise analyses.

Although a great degree of reservation is indicated in the use of the ear as a noise measuring instrument, the ear can provide some helpful information in the screening survey. It is especially useful in determining if the noise will interfere with speech.

If there is difficulty in carrying on a conversation at a close distance or in speaking on the telephone, this indicates there may be need for further study to determine if there may be a problem of a potential hearing loss. This would certainly indicate that the intensity levels in the speech communication frequencies are high.

Site Location

In a screening survey a large number of measurements are usually taken with the sound survey meter or sound level meter throughout the area with particular attention to the noise sources.

In recording data it is helpful to have a blueprint or sketch of the building or room on which measurements can be noted by location. Frequently, the location of supporting columns in a building can be used to form a grid system such as shown in Figure 1.

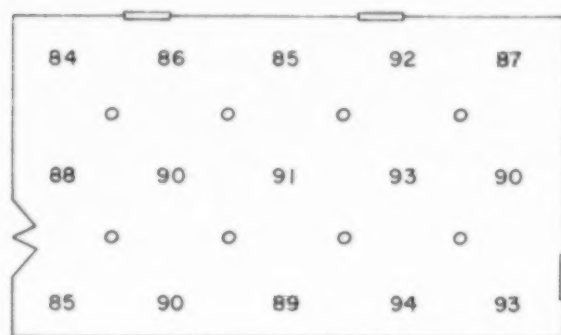


Figure 1

Procedure and Recording of Data

The procedure for conducting a screening survey is less rigid than for the other surveys. This does not mean that completeness and accuracy can be sacrificed. In making the survey, the area should be covered completely in some orderly fashion. A walk-through basis is usually sufficient as long as time is taken to record the following essential information:

1. Equipment used for the measurements.
2. Location in plant (supplement with diagrams).
3. Sound pressure levels.
4. Machines which are operating.
5. Number of employees exposed and duration of exposure.
6. Characteristics of the noise.

This list could be extended to include all of those items necessary for the more detailed survey; however, the individual conducting the survey should use his own judgment in recording this data other than that essential to fulfilling the objective of the screening survey.

Interpretation of Results

On the basis of the selected criteria, it is possible to decide on the need for more detailed surveys. For example, suppose that the noise criteria were established on the basis that all noise greater than 90 dB would eventually cause noise-induced hearing loss, and it was the concurrent opinion of management that noise-induced hearing loss should be at an absolute minimum. Then on the basis of a screening survey all areas showing a sound pressure level greater than 90 dB should be investigated more thoroughly. The investigator may wish to allow a greater factor of safety by using 80 or 85 dB. By the same token more risk would be assumed by using 95 dB.

The General Noise Survey

Purpose

The general noise survey is made to determine the characteristics of a noise and its potential effect on individuals. This type of survey can be made to evaluate a potential hearing loss, speech interference level, or an annoyance problem.

Equipment

The minimum equipment necessary for a general survey would be a sound level meter, octave band analyzer, and acoustical calibrator. In some special situations when the sound energy is concentrated in a narrow band or is a pure tone, it might be necessary to use a frequency analyzer with a band width which is narrower than one octave or it may be desirable to measure peak sound pressure levels with a peckmeter or oscilloscope from impact or impulse noise sources.

Site Location

In the evaluation of noise exposure to individuals the microphone would be placed as near to the individual as possible without interfering with his work. Several measurements should also be made with the sound level meter in the area to determine if the sound pressure level is relatively uniform and to ascertain if the measurements being made represent the individual's exposure.

It may be necessary to make a number of measurements in order to determine accurately the noise levels and individual exposure. This will be the case if the machine is operating only part of the time or is cyclic in operation. Also if an individual works in a number of locations, it will be necessary to make measurements at all locations.

Procedure and Recording of Data

One important part of making a noise survey is the recording of sufficient data. The data recorded will depend on the purpose of the survey; that is, whether it is a hearing loss, speech interference, or annoyance problem. To a certain extent each noise survey is unique, and the report must fit the requirements of the particular situation. There are, however, certain basic data which are essential and must be recorded in almost all cases:

1. Equipment used for the measurements and type and serial numbers of all microphones, sound level meters, and analyzers.
2. Corrections for measured values, such as cable, temperature, and acoustical calibration.
3. The time and date of the survey and name of the person conducting the study.
4. Description of space in which the measurements are made, such as, the dimensions and nature of floor, walls, and ceiling and the location of doors and windows.
5. Description of the noise source under study (primary noise source). This should include a clear description of the machine (size, nameplate data, speed and power rating, types of operations and operating conditions), the number of machines in operation, the locations of the machines, and the types of mountings.
6. Description of secondary noise sources, including location and type of operations.
7. Noise control measures in use, including the types and effectiveness of ear protectors.
8. Overall and octave band levels at each microphone position and the extent of meter fluctuation.
9. The meter speed and weighting network used.

Page of

Other Equipment: _____

Location: _____ Sketch _____

[illegible]

Remarks: _____

Recorded by: _____

Figure 3

10. Position of the microphone and the direction of the sound with respect to the microphone. Tests for standing wave patterns and the decay of sound level with distance.
11. Time pattern of the noise; that is, whether continuous or intermittent and impact and duration of the exposure.
12. Personnel exposed, directly and indirectly.

It is helpful to have a survey data sheet on which the data can be recorded. Two typical survey data sheets are shown in Figures 2 and 3.

Interpretation of Data

After a survey has been completed and before a report can be prepared, it is necessary to analyze the data. The necessary corrections, if any, must be made and the accuracy of the final results determined. Then the appropriate criteria or standard, as discussed in Section N-5, should be selected and this should be compared with the data.

It is useful to plot the results of the survey on a graph (Figure 4) showing the intensity (decibels) versus the frequency (octave bands). The appropriate criteria can also be plotted on the same graph paper. The frequencies in which the data exceeds the criteria indicate those frequencies in which noise reduction is necessary and the amount of reduction necessary.

Special Noise Surveys

Purpose

This category includes those surveys made for research and noise control. It is usually necessary to make a large number of measurements to clearly define the exposure or the exact nature of the noise source.

Equipment

The equipment necessary for this type survey will vary considerably. For some surveys all the equipment required will be a sound level meter, octave band analyzer, and acoustical calibrator. In other surveys it may be necessary to use one or more of the following instruments: narrow-band analyzer, impact noise meter, tape recorder, oscilloscope, graphical level recorder, statistical distribution analyzer, and dosimeter.

Site Location

When measurements are made for research purposes, the nature of the research will determine where the samples are taken. In the case of noise control, measurements would be made to determine the total acoustical output and the directional characteristics of the source. Measurements at one point yield information about that location, in that environment only. In order to determine how the noise energy of the source differs at another location, the acoustical power characteristics must be determined at that location. A number of measurements must be made in a geometrical pattern about the source and at some uniform distance from the source. This may also involve selective measurements to locate the main source of the noise emitted from the equipment.

Procedure

It is very difficult to outline a standard procedure for this type of survey. Extra care should be exercised in the calibration of equipment and in making certain that the measurements are accurate for this type of survey. It is also necessary to take an ample set of notes. Describe the exact conditions while making the measurements so that they can be repeated if necessary.

Conclusions

With the proper selection and use of noise measuring equipment it is possible to obtain accurate and meaningful

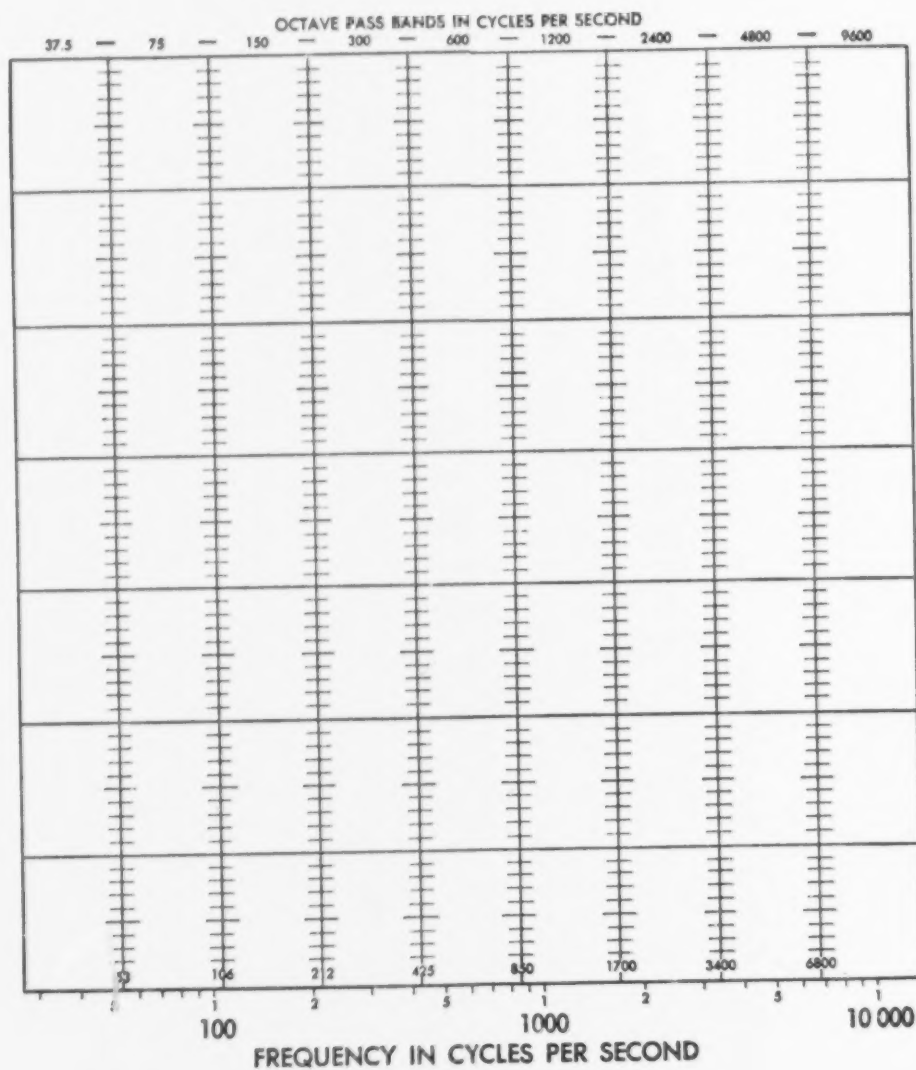
evaluations of noisy environments. It is necessary, however, to be familiar with the equipment and its limitations and other factors which may influence the performance of the equipment in a particular environment.

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NO. 31.460. SOUND ANALYSIS BY OCTAVE BANDS.

OCTAVE BAND LEVEL IN DB RE 0.0002 MICROBAR



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Figure 4

N-7-11

HEARING CONSERVATION PROGRAM

The occurrence of hearing loss due to occupational factors depends on individual susceptibility to noise and on the character and extent of noise exposure. This means that a team approach is indicated, involving a well-rounded program with both environmental engineering control and medical conservation measures.

The Ford Motor Company in its Medical Guide on Hearing Conservation Program⁽¹⁾ lists basic inclusions in a hearing program, but also goes further in stating that a plant hearing conservation committee should include (among others) the plant manager, plant physician, industrial relations manager, labor relations supervisor, safety engineer, and the plant engineer. It may be seen, then, that a medically oriented program cannot stand alone, but must be conducted in cooperation with other members of the employee-union-management team.

Environmental engineering controls are dealt with in detail elsewhere in this manual but in essence, these include diminution of noise at its source, as decrease in the noise transmitted through air or building structures, and a change in operational procedures, such as rotation of employees in noisy jobs, personal protection, and other methods of control.

As indicated in the first paragraph, the medically oriented program must encroach on some of the engineering areas in order to provide an integrated conservation program. The medical program of the Scott Paper Company involves:

1. Identification of work areas where noise is a hazard.
2. Elimination of noise at its source, whenever possible.

3. Prevention of hearing loss among employees through:

- a. Providing for the detection of hearing loss before it becomes disabling.
- b. Providing protective devices for employees who work in areas where noise is of potentially harmful density.⁽²⁾

The strictly medical hearing conservation program may be outlined as follows:

1. Early identification of those susceptible to noise induced hearing loss.
2. Keeping of proper records.
3. Supervision of a personal protection program.⁽³⁾

The early identification of susceptible individuals involves general physical and audiometric examinations of all new employees, as well as periodic examinations among continuing workers exposed to noise. The preplacement examination provides base-line information as well as giving the medical department information relative to previous hearing loss, ear infections or other abnormalities, and previous exposure to noise. Placement examinations involve the as-yet-unanswered question as to whether a partially deaf person might well have a built-in ear defender and not be as susceptible to further noise exposure as one with normal hearing. Periodic examinations provide the medical department with data regarding individual variations among employees exposed to noise, with clues as to areas in the plant which need further investigation from the engineering point of view, and with information relative to which employees should be provided with hearing protection. One authority⁽³⁾ recommends that all employees be examined within ninety days after being hired to determine individual susceptibilities and idiosyncracies.

Prepared by: William S. Lainhart, M.D.

A personal hearing protection program involves the placement of a barrier between the noise source and the inner ear when it is impossible to reduce the noise at its source or to provide acoustical barriers around the noise source. Ear protection devices are discussed in detail in other parts of this manual but in general such devices must be devised to protect against sound reaching the inner ear through seal leaks between the protector and the head, through the material of the protector itself, through vibration of the protective device, or through bone and tissue conduction. The medical department must then be aware of the problems involved with proper fitting of the various types of protectors and must have a program for indoctrination of workers in the initial phase of adaptation to the protectors as well as the need for continued use throughout the period of noise exposure.

Industrial hearing protection programs cannot be accomplished without full support from top management, supervisory personnel, and the individual worker. Although such programs have not always been successful in the past⁽⁴⁾, the pervading attitude must continue to be based on the notion that by these efforts, noise induced hearing loss will be prevented, at least in part, and will not become a serious handicap to the individual worker in the noise environment. Dr. Maas⁽⁵⁾ has indicated that a large part of the failure of hearing

conservation programs is due to lack of management interest and support. From the management point of view this lack of cooperation apparently manifests itself in the "ostrich" approach, in the lack of a continued follow-through approach and a defeatist attitude early in the program. Workers, on the other hand, object to the nuisance of wearing protective devices, fear placing a foreign object in the ear, and feel that protection is unimportant.

The solution to the failure of hearing conservation programs is not simple. Dr. Maas⁽⁵⁾ has pointed out methods and techniques for overcoming many of these objections. Some of the methods found to help in the promotion of hearing conservation are personal demonstrations by responsible supervisors and officials; providing medical or nursing competency to explain the program and to fit individuals properly; the development of a definite wearing schedule; and the continuing education program among workers at all levels from the man on the line through top management.

Thus, it would appear that a total program directed toward conservation of hearing among employees "... hinges on the full support of management, a well-informed and interested medical department, a continuing effort and a considerable amount of patience."⁽⁶⁾ In addition, a continuing education program among all employees is essential.

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AUDIOMETRY

Introduction

Audiometry is the measurement of hearing. It is of importance and concern because it is crucial to any effective hearing conservation program. Audiometry is used to determine whether or not the hearing of workers is being adversely affected by noise. In this sense, the measurement of hearing is the primary means for gauging the success of a program for hearing conservation. Audiometric data must be pertinent and reliable in order to be useful rather than misleading. The type of hearing test employed and the conditions under which it is conducted are of direct concern, therefore, and will be considered in some detail in the sections that follow. In essence, audiometry consists in eliciting meaningful responses to specified sounds. This requirement is met, in part, when a standard test is administered by an operator trained to recognize a meaningful response as it occurs, and when the listener has been instructed as to what is expected of him and cooperates to the extent of responding appropriately. The presentation of specified sounds requires consideration of the purpose of the test, the type of test needed, and the characteristics of the test instrument. Furthermore, so that only the desired sounds are presented during the test, attention must be directed to providing a test environment that excludes unwanted or interfering sounds. With the foregoing in mind, the following is a brief discussion of audiometry, particularly as it applies to hearing conservation in industry, and the characteristics of audiometers and the test environment.

Audiometric Tests

General

Hearing tests can be classified in any of a number of ways. One method of classification is based on the nature of the sound stimulus used, such as pure tones, speech, and noise. A second method has to do with the function under test. This may relate to threshold (sensitivity) for sound detection, to discrimination (acuity) among sounds, or to thresholds for detecting differences (difference limen) between sounds. Third, some designation may be assigned as to whether the test is administered to individuals or to groups. Fourth, classification may be made in terms of purpose as related to diagnosis, screening, or monitoring. Fifth, certain specific designations apply to some standard tests named for their originators (Weber test, Stenger test, etc.), for the function being measured (loudness balance, speech discrimination), and so on. Sixth, tests sometimes are referred to as air conduction or bone conduction types, according to the means of stimulus presentation. Seventh, tests are also being designated with regard to the method of administration as manual, semi-automatic, or automatic. Other classifications are possible and may be applied if they serve a useful purpose. The instruments used for testing hearing tend to be classified in similar fashion.

It is important to keep in mind that there is no direct test of hearing. Usually the listener is asked to indicate by raising a finger, repeating words, or pushing a switch when he hears the test signal. This provides an indirect measure of hearing based upon behavioral signs, which are related to hearing only by agreement between the tester and the listener, and requiring the active cooperation of the listener. The tester should be capable of judging whether or not the response given by

Prepared by: Paul J. LaBenz, Sc.D.

the listener is plausible and acceptable, or whether further instruction and testing are required. This is not always easy to do even after considerable experience has been gained. Otological and audiological supervision of a hearing conservation program is recommended for this reason. Test results that reveal significant amounts of hearing loss suggest referral for additional examination because factors other than noise may operate to affect hearing and hearing tests.

The Pure Tone Threshold Test

The pure tone threshold test is the one most often used and recommended for use in hearing conservation programs. The following are three of several good reasons for using this test procedure:

- 1) It is relatively simple to administer and to perform. Any reasonably intelligent person can be instructed in a short time to conduct routine pure tone tests. The demands upon the listener are likewise minimal so that even fairly inexperienced persons can perform satisfactorily after brief instruction. Furthermore, the test equipment required is readily available at modest cost.
- 2) It is a sensitive indicator of changes in the hearing mechanism. Hearing sensitivity to various frequencies bears some relationship to the functional anatomy of the ear. Changes in sensitivity may be an early signal of a developing hearing defect and may provide a clue to the locus of the problem as well. In contrast, speech audiometry is generally less sensitive to minor changes in audiometric configurations; that is, small changes in the pattern of sensitivity to frequency may occur without affecting the threshold for speech or its discrimination.
- 3) It is sufficiently standardized for

broad application. The physical characteristics of pure tones are more precisely specifiable and, therefore, reproducible than complex stimuli such as speech. This fact enables virtually universal administration of the test and the comparison of results with reasonable assurance of validity.

The test usually is administered individually and manually except when large groups of persons must be tested on a continuing basis, as in a military environment. In practice, the listener is instructed to signal (preferably by raising a finger or hand) each time he hears or thinks he hears a faint tone and to stop signalling when he does not. The earphones are positioned carefully over each ear by the tester, who then selects a frequency (usually 500 or 1000 cps) by means of a knob on the audiometer, adjusts the attenuator to a low but easily audible level of 30 dB, and presents the tone to the desired ear by actuating the tone switch. If this initial tone is not heard, the level is increased by successive 10 dB steps until the listener signals that he hears it. When the listener signals that he hears, the level is decreased by 10 dB and the tone again is presented. This step is repeated several times until the listener fails to signal that he hears; the tone then is increased in steps of 5 dB until heard once again. In this manner three or four ascents and descents are made across the values at which the tone is just heard and not heard. Threshold is considered the lowest value in multiples of 5 dB at which the tone is heard as the level is increased from inaudibility to audibility (ascending method). An accepted psychophysical method defines threshold as the point where 50% of the responses are positive. In actual audiometric practice, using increments of 5 dB, threshold may be found to be from 50% to 100% of positive responses. This is because the listener may not respond at all at one level but may respond consistently at the next higher level.

An alternative procedure for threshold measurement is one wherein test tones are presented initially at the lowest level possible (0 or -10 dB). If the tone is not heard at this level, it is increased by 10 dB steps successively until a hearing response occurs. Then the level is decreased by 10 dB one or more times until the tone no longer is heard. Thereafter the level is alternately increased by 5 dB steps until the tone is heard again and reduced by 10 dB steps until it is not heard. Threshold is the lowest level at which an increase of 5 dB elicits a hearing response to two of three tone presentations at that level or, as frequently happens, the lowest level at which two successive responses occur. The method is rapid and reasonably accurate. It has the additional advantage of introducing tones initially near the listener's threshold so that he does not form an inflated criterion of minimum audibility. Whichever procedure is adopted should be used consistently in the testing program.

After the threshold has been measured for one frequency, the tester turns to the next frequency and repeats the measurement procedure. Generally the test is started at 500 or 1000 cps and continued upward in frequency in octave and half-octave intervals to the upper frequency limit; then 500 or 1000 cps is measured again, after which the frequencies below this point are measured in octave intervals. The second measurement at 500 or 1000 cps gives some indication of the reliability of test responses by the listener. Quite often the second value obtained at 500 or 1000 cps is 5 dB better than the first, particularly in the case of inexperienced listeners. In this event, the better (lower) of the two values is accepted as threshold and no further consequence is made of it. If the difference on retest is 10 dB or greater, the higher frequencies should be tested again. Inconsistent responses leading to markedly disparate threshold values

are reason to refer the listener for more careful testing by an audiologist because some function factor may be operant. Such a factor need not necessarily have its locus in the auditory system.

The test frequencies most pertinent to an industrial hearing conservation program are 500, 1000, 2000, 3000, 4000, and 6000 cps. These frequencies include the most useful range of hearing as well as those frequencies most likely to show changes as a result of exposure to damaging levels of noise. Frequencies above and below these listed are more likely to be influenced by factors such as age, non-noise-induced hearing problems, and masking effects by ambient noise during test. In view of the limited number and range of frequencies recommended for test purposes, it seems reasonable to begin testing at 500 cps (rather than 1000 cps), to test each of the frequencies in ascending order, and to recheck at 500 cps. Tests should then be made on the other ear using the identical procedure.

Test tones should be presented to the listener with a duration time of about one second and should be spaced by intervals of silence varying in length up to several seconds. Tone presentations should be unpredictably aperiodic so as to prevent habituation or guessing, which can result in rhythmic but irrelevant responses by the listener. It is also a sensible procedure always to begin testing on the same side of the head each time. If a correction factor needs to be applied at some later date (to compensate for practice effects, for example), it is more easily done if the test procedure has been standardized. Needless to say, the proper phone must be used on each ear. It is considered a wise precaution against incorrect earphone placement to ask the listener to signal with his right hand when he hears with his right ear and to use the left hand when he hears with the left ear.

The threshold values measured at each frequency should be recorded appropriately and preserved. The audiogram is one means of recording such data. The standard audiogram is a graphic form on which the frequencies in cycles per second appear as values along the abscissa, and the hearing level in decibels along the ordinate. The form is arranged so that 20 dB of hearing level occupies space equivalent to one octave in frequency. Hearing levels traditionally are recorded so that deviations from normal values in hearing are plotted as deviations from zero hearing level, with larger deviations plotted toward the bottom of the graph. The symbols in general use are "O" for the right ear, and "X" for the left. If colors are used, the custom is to use red for the right ear and blue for the left. This symbolism is easily remembered as "right, round, red."

Threshold data are recorded and stored more conveniently for most purposes by simply writing the numerical values in tabular form on a record card. This method requires less space, enables chronological listing of test results, and reduces the likelihood of error which occurs when data are transferred from numerical values on the audiometer to points on the audiogram. Some audiometers of the automatic or semi-automatic types are self-recording.

The Pure Tone Screening Test

For some purposes it is not necessary to know precise threshold values. It may be important to determine only if hearing levels lie within a limited range relative to normal hearing. If such is the case, a screening procedure may be established. Depending upon the purposes to be served, a level is selected (e.g., 15 dB) and a number of frequencies are presented to each ear at the selected level. This is, in effect, a pass-fail test for finding out in a large population those individuals who either qualify for a category, or are disqualified and require

some further attention. A procedure of this type can be used for monitoring purposes when large groups are involved and frequent periodic checks are needed. Individuals who are noise-sensitive can be identified in this manner and referred for more careful testing. Those who pass the screening test will require no further attention, except possibly for an annual test, with a consequent saving of time. When properly organized, the screening test can be conducted in about one minute per person by limiting the frequencies tested to no more than four. It is important to keep in mind that this kind of test is not a substitute for the threshold test, which yields numerical values rather than gross categories.

The Hearing Testing Program

Every program for the conservation of hearing must include a program of hearing measurement. The success of any hearing conservation effort is based upon the prevention of deteriorative changes in hearing ability among the persons exposed to noise. Logically, then, it is important to know the state of a person's hearing at the onset of exposure as well as periodically thereafter. The routine of hearing testing should include initial pre-employment audiograms as well as follow-up tests.

The following material which pertains to the testing program is based largely upon recommendations published (1964) by the Committee on Conservation of Hearing of the American Academy of Ophthalmology and Otolaryngology.

Initial Tests of Hearing

The initial test of hearing, ideally a pre-employment test, serves as a reference line. It should be a pure tone air-conduction threshold test and should be performed on all employees, including those who may never be exposed to noise. The audiogram obtained provides a baseline against which changes, if any, can be measured. It will also serve to

identify individuals with existing hearing problems, which may be amenable to correction by medical treatment or which may become aggravated, if neglected, and result in the loss of trained workers or in litigation. The initial audiogram can also identify those with the good hearing required for particular jobs. Because of its importance, the initial test must be a threshold rather than a screening test.

The frequencies recommended for industrial programs are 500, 1000, 2000, 3000, 4000, and 6000 cycles per second. If the hearing levels measured at 500, 1000, and 2000 cps average more than 15 dB in the initial test, the employee should be referred for otological examination and placement evaluation. Referral is suggested also whenever the audiogram shows any unusual feature such as an abrupt drop in sensitivity beginning at 2000 cps or lower. The hearing levels mentioned refer to the American Standard (Table I) rather than to the proposed International Standard not yet adopted. The average level of 15 dB for 500, 1000, and 2000 cps lies just within the limit of the range of normal hearing as defined by the Committee on Conservation of Hearing. Hearing impairment is considered to begin when the level at these three frequencies averages 17 dB. Hearing tests should not be given sooner than sixteen hours after the last noise exposure. The reason for this is that exposure to noise can cause temporary changes in hearing sensitivity (temporary threshold shift), recovery from which may occur slowly.

Follow-up Tests of Hearing

The number and frequency of follow-up tests depend upon the severity of the noise problem involved. In any case, tests should be done at least once each year. The first follow-up test should be made nine to twelve months after job placement, unless exposure involves levels greater than 100 dB averaged for the three octave bands between 300 and

2400 cps. In this case, the first test should be made about ninety days after job placement. Other indications for early follow-up are complaints of ringing in the ears (tinnitus) or other such head noises, excessive temporary threshold shifts, or unusually slow recovery from temporary threshold shifts. Follow-up tests should be made not less than sixteen hours after the most recent noise exposure, preferably longer if possible. If changes in hearing are 10 dB or less relative to the initial audiogram, it is sufficient to make subsequent follow-up tests at yearly intervals unless some other indication arises. Changes of 10 dB or greater occurring at 2000 cps or lower than changes of 15 dB or greater at 3000 cps or higher frequencies suggest that additional steps need be taken to conserve that person's hearing.

Whereas the initial test should always be a threshold test, the follow-up test may be either a threshold or a screening test. The threshold type of test is always preferred because it gives more information. Practical considerations may make it necessary to use screening procedures for follow-up. It should be emphasized that a screening test is a dichotomizing test, which permits only two statements that hearing is at least as good as or that it is worse than the standard used. When a screening test shows a significant change in hearing (see preceding paragraph), it should be followed by a threshold test by way of confirmation.

As more frequencies are used in the screening test, more information is provided and, of course, more time is required. In order to conserve time, screening is sometimes done at the single frequency of 4000 cps as a gross check. The advantages cited are:

- (1) it can be done in a few seconds;
- (2) it can be done by minimally trained persons; and
- (3) it can be done in any reasonably quiet place if tone levels of 20 dB or higher are used.

However, the suggestion is also made that two or more screening levels at least 15 dB apart should be used so that changes of the order of 15 dB can be detected. The objections to the single frequency screening at 4000 cps are:

- (1) it is more subject to error than other methods;
- (2) it requires as much time to screen one frequency at two or more levels as it does to screen with two or more frequencies at one level; and
- (3) it does not accurately indicate changes at other frequencies when the threshold at 4000 cps is 50 dB or greater.

In a large population of individuals who are exposed to noise, the shifts in thresholds are found to occur most often in the higher frequencies between 3000 and 6000 cps. However, some individuals, when exposed to certain types of noise, show appreciable changes in hearing at lower frequencies. These changes would very likely be missed by single frequency screening tests. Though the Committee on Conservation of Hearing considers single frequency screening at 4000 cps permissible, it is by no means a desirable procedure and should be adopted only if no other measure is possible. One further consideration should be kept in mind: the pure tone threshold test should be done whenever significant change is indicated by screening tests. Screening procedures with the possibility of a high margin of error can erroneously indicate change where, in fact, none has occurred. This can result in an unnecessarily large number of threshold tests and, consequently, a spurious economy in time.

Evaluation of Audiometric Changes

In order to establish that a change in hearing status has actually occurred, it is recommended that three successive threshold tests be made under similar conditions on different days at least

sixteen hours after exposure to noise. The three audiograms are considered consistent if they agree within 10 dB at four of the six test frequencies (500, 1000, 2000, 3000, 4000, and 6000 cps). If they are not consistent, the person should be given a special examination to determine the reason. The audiogram with the lowest dB level averaged at 500, 1000, and 2000 cps represents the hearing status. The average should be derived from a single audiogram, not a composite of several audiograms. In the particular case the cause of change should be determined by medical authority. However, it is well to be aware of some of the factors that may contribute to inconsistencies and inaccuracies in audiometric testing. Some of these are listed below:

A. Physical Variables

1. Equipment variables such as calibration, attenuator accuracy, type and condition of earphone cushions, hum, switch clicks, and other instrument noises.
2. Ambient noise level in test room.
3. Placement of earphones.

B. Methodological Variables

1. Testing technique and consistency of method used.
2. Elapsed time between tests.
3. Clarity of instructions to listener.
4. Type of response required from listener.
5. Test order of frequencies.

C. Physiological Variables

1. Ear disease or related pathology.
2. Condition of general health of the listener.
3. Temporary threshold shift.
4. Presence of interfering head noises.
5. Age of the listener.

D. Psychological Variables

1. Motivation of the listener.
2. Attitude toward the test and tester.
3. Attentional factors.
4. Comprehension of instructions.
5. Experience in taking tests.

Audiometers

Types

As in the case of audiometric tests, it is possible to classify audiometers in a variety of ways. The various methods of designation represent points of view and are not necessarily mutually exclusive. The pure tone audiometer is the type in widest general use. It has been the practice to further classify the pure tone audiometer in terms of:

- (1) Purpose (diagnostic, clinical, screening, etc.);
- (2) Inherent features (wide range, limited range, narrow range);
- (3) Administration capability (individual, group); and
- (4) Degree of automation (manual, semi-automatic, automatic).

It is possible for an audiometer to bear several designations simultaneously, e.g., to be classed as a limited range, pure tone, automatic group audiometer. There is a tendency for the terms "diagnostic and clinical" to be supplanted by the term "wide range," and for screening to be replaced by the terms "limited range" and "narrow range." Most of the audiometers in existence today are probably of the wide range, individual, manual type having fixed (discrete) frequencies.

Fully automatic audiometers are relatively rare and not readily available commercially. At least two semi-automatic instruments are being marketed. These control the presentation of frequencies, but leave the manipulation of levels to the listener, with provision for a graphic record of the listener's

changes. The operator must instruct the listener, start the apparatus, and watch to see that the test is carried out properly. The semi-automatic audiometer enables several tests to be conducted simultaneously. Of course this requires multiple installation of audiometers and test rooms. One of the advantages cited is that it reduces operator fatigue and error. However, the installation cost is considerable and the saving in time does not warrant this expenditure at present.

Speech audiometers are another class of instruments used to measure hearing ability. Standardized lists of words and other speech materials can be presented either by recordings or by live voice to a listener at controlled intensities. Two common measurements are the threshold for hearing speech and the discrimination score for speech at supra-threshold levels. These measurements are very useful in diagnostic and rehabilitative efforts, but have found less acceptance than pure tones in hearing conservation programs. As previously mentioned, considerable variation in audiometric configuration can occur without appreciably affecting the ability to understand speech. Speech testing circuitry is frequently incorporated in pure tone audiometers. Speech audiometers also can be either of the individual or group type.

Specification for Audiometers for Hearing Conservation Programs

In order to insure that the results of hearing tests performed with various instruments will be comparable, the American Standards Association devises minimum criteria which must be met for acceptability. These criteria are revised from time to time and represent a compromise between the ideal and the practical standard. A new set of specifications has been proposed to replace the 1951 standard. The material presented here is drawn from this proposed standard, which will probably be adopted. The reader is urged to obtain a copy of

the new standard from the American Standards Association (10 East 40th St., New York) when available.

The proposed standard distinguishes three types of pure tone audiometers as wide range, limited range and narrow range. The wide range type (see Table I) must provide at least nine frequency ranges (250, 500, 1000, 1500, 2000, 3000, 4000, 6000, 8000 cps; 125 and 750 cps optional) and a wide range of levels (70 dB at 125, 80 dB at 8000 cps, 90 dB at 250 and 6000 cps, and 100 dB at all other frequencies) above the standard reference threshold. In addition, there must be provision for testing by bone conduction and masking. The limited range audiometer need have only the frequencies 500, 1000, 2000, 3000, 4000, and 6000 cps, and output levels of at least 70 dB above the standard threshold reference level. No provision for masking and bone conduction are required by the specifications. This type is generally adequate for most hearing conservation purposes, although occasionally a loss greater than 70 dB may be encountered, particularly in the higher frequencies. The narrow range audiometer is any instrument with more restricted facilities than specified for the limited range instrument. Apart from these distinctions there are general and specific requirements which apply alike to all audiometers.

General requirements include the following:

- (1) Frequencies of pure tones must be indicated in cycles per second, and the hearing threshold level must be indicated in decibels.
- (2) The audiometer shall have a name plate showing the manufacturer's name, the model, serial number, voltage and frequency of power supply needed, and power consumption.
- (3) Means must be provided for testing the condition of the batteries, if so powered.

- (4) The ear not being tested must be covered by a phone, either operable or a dummy. If both phones are operable, both must meet specifications, and switching arrangements for testing each ear must be provided; color coding is required if each phone is not permanently attached to its proper circuit.
- (5) A spring headband is required to hold the earphones against the ears and to provide an adequate seal.
- (6) Audiometers must be free from electrical shock hazard. Shock hazard exists when the open circuit potential of an exposed part to ground or to another exposed part is more than 30 volts and the current through a 1500 ohm resistor is more than 5 milliamperes.
- (7) The audiometer must meet specifications after a warm up time of thirty minutes.

Specific requirements for audiometers are:

- (1) *Accuracy of tone frequencies.* Each of the frequencies generated by the audiometer shall have a value within 3% of the indicated frequency. If the audiometer generates continuously variable rather than discrete frequencies, the tolerance limit may be 5%.
- (2) *Purity of tones.* The sound pressure level (developed by the earphone in a standard coupler) of any harmonic above the fundamental must be at least 30 dB below the sound pressure level of the fundamental at full audiometer output. This provision is to insure that persons with abrupt changes in sensitivity are being tested at the intended frequency and are not responding instead to a harmonic of that frequency.
- (3) *Dial Readings of Hearing Threshold Level* shall extend from zero dB to the required level of output

(see Table I) by intervals of 5 dB or less. The indicated difference between two successive designations on the dial shall not differ from the actual meas-

ured difference by more than either three-tenths of the dial interval (measured in terms of dB) or by 1 dB, whichever is larger.

Table I

Freq. cps	Reference Threshold Levels		Frequency and Output Required	
	ASA 1951	ISO 1963	Wide Range	Limited Range
125	54.5	45.5	70*	--
250	39.5	24.5	80	--
500	25	11	100	70
1000	16.5	6.5	100	70
1500	(16.5)	6.5	100	--
2000	17	8.5	100	70
3000	(16)	7.5	100	70
4000	15	9	100	70
6000	(17.5)	8	90	70
8000	21	9.5	80	--

Values given to the nearest 0.5 dB. () Indicates interpolated value.

*Indicates optional.

(4) *Accuracy of Sound Pressure Levels.*

As referred to the standard reference level, the sound pressure level produced by an earphone shall not differ from the indicated value at any reading of hearing threshold level by more than 3 dB at the frequencies 250 to 3000 cps inclusive, by more than 4 dB at 4000 cps, nor by more than 5 dB for other frequencies outside of this range.

(5) *Unwanted Audiometer Sounds During Test.*

The test earphone must not produce any undesired sound of sufficient magnitude so as to interfere with threshold judgments by the listener. Undesired sound in the earphone that is not being used for the test must be at least 10 dB below hearing threshold level, when the audiometer is set for 60 dB hearing threshold level, and at least 70 dB below the signal in the test phone at levels above 60 dB hearing threshold levels. There

shall be no audible sound or radiation from the audiometer during operation at any setting of the hearing threshold dial up to 50 dB, as determined by a listener with normal hearing wearing disconnected earphones in the regular test position. The audiometer output during this test is absorbed by a resistive load equivalent to the impedance of the earphone at 1000 cps. The purpose of this test is the prevention of spurious listener responses caused by extraneous non-test sounds produced by the instrument.

(6) *Tone Switch.*

Both wide and limited range manual audiometers must have a switch for the presentation of tone signals to the listener by the operator. The switch should be of the "normally off" type but should be capable of "normally on" operation as well. It must present and remove tones without audible clicks or transients.

The time required for the tone to rise from -20 DB to -1 dB relative to its final steady state shall not be less than 0.02 second and not more than 0.1 second. The time required for the tone to decay by 20 dB shall be not less than 0.005 second and not more than 0.1 second. When the tone switch is actuated either manually or automatically (pulsing), the rise time to within -1 dB of final steady value or the time for decay by 20 dB must not exceed 0.15 second. The tone switch must not cause the output to overshoot the steady value by more than 1 dB at any time. In the "off" position the steady value of output voltage must be at least 50 dB below the steady value in the "on" position, or at least 10 dB below the value corresponding to Zero Hearing Threshold Level, whichever of these two levels is higher.

- (7) **Stability.** When measured at the 60 dB hearing threshold level at 1000 cps, the audiometer rated for 117 volt operation must meet specifications for purity of tones and for accuracy of sound pressure levels with no more than 2 dB variation as the supply voltage varies from 105 to 125 volts. Equivalent ratios of ranges apply to other operating voltages. The same specifications regarding purity of tone and accuracy of sound pressure levels apply when the instrument operates continuously at the proper voltage in a range of ambient temperatures of at least 60°F to 90°F for at least one hour.
- Audiometer Acceptability.** Most of the audiometers produced by established manufacturers are designed to meet at least the 1951 standards. Recent models generally exceed the old standard and for the most part meet the proposed new standards. The pur-

chaser must rely upon the claims of the manufacturer or submit the instrument in question to the necessary series of tests. The Sub-Committee on Audiometers of the American Academy of Ophthalmology and Otolaryngology supervises the testing of audiometers and publishes, in the Transactions of the American Academy of Ophthalmology and Otolaryngology, a list of audiometers that meet the standards. The audiometers tested are submitted voluntarily by the manufacturers to one of two established laboratories. The cost of testing and shipping is borne by the manufacturers. This being the case, the fact that an audiometer is not listed by the AAOO does not signify that it is necessarily sub-standard. The instrument may not have been submitted for test, or tests may not have been completed at the time the list was published. Furthermore, no additional monitoring checks are made after the initial test. Listing does not mean continuing checks on quality in subsequent production by that manufacturer, nor that the particular instrument listed continues to operate as tested. If an instrument is listed, it means only that the manufacturer is demonstrably capable of producing an acceptable instrument.

Calibration of Audiometers

It is necessary to verify periodically that an audiometer is performing in conformity with the standards. There are prescribed methods for accomplishing such checks. The most precise method requires certain pieces of equipment of a fairly specialized nature. Less precise but highly useful information can be obtained by measuring a known population and comparing results.

Physical Calibration. The exacting

procedures involved in actual physical measurement of the audiometer output are usually performed in the calibration facility of the manufacturer or a similar well-equipped laboratory. Calibration involves not only measurement but correction when indicated. Checks are made at least of frequencies, attenuator steps, and the sound pressure output of the earphones as follows:

- (1) Frequency check requires leading the output of the audiometer to an electronic counter or to an oscilloscope to determine whether or not the dial-indicated frequency is within the standard tolerance limits.
- (2) The attenuator check is made by measuring the voltage change which occurs when a given change in the attenuation setting is made. The voltage changes must be proportional to the changes in attenuator dial readings within the limits specified in the standards.
- (3) The sound pressure output of the earphones is measured with the hearing threshold level set at 60 dB. The earphone is placed on a machined coupler containing a cavity with a volume of 6 cc when bounded on one side by the earphone and on the other side by a condenser microphone. The sound pressure output of the earphone is transduced by the microphone and read as electrical values which, when corrected for 60 dB output, should yield the reference threshold values given in Table I.

Physical checks and calibration should be done at least annually, or whenever biological checks suggest that an appreciable error exists.

Biological Calibration. A small group of from three to six otologically normal young adults (below age 25) with known good hearing should be tested every three months. The threshold values for

this group should lie within 5 dB of the audiometer zero hearing level. If they do not, corrective measures are in order. Correction factors may be applied to test results temporarily if the discrepancy is small and limited to only one or two frequencies per phone, but physical calibration should be performed as soon as feasible.

The audiometer operator should test his own hearing at all frequencies once each week, assuming that he has normal hearing. Otherwise, some other listener with known normal hearing should be used. Discrepancies of as much as 10 dB will indicate that the audiometer should be checked on the calibration group.

The audiometer operator should listen at the beginning of each day to all frequencies in each phone, and check one or two frequencies at his known threshold. It is a precaution well taken to manipulate the attenuator at several levels above threshold by way of a gross check on attenuator function and possible instrument noise.

The results of hearing tests are no better than the audiometer will permit. It is necessary to devise a routine system of checks such as suggested, so that the hearing conservation program data can be regarded with some confidence.

Audiometric Test Environment

The presence of extraneous sounds can interfere with accurate determination of thresholds by distracting attention or by masking the test sounds. Masking is defined as the increase in the threshold of a sound caused by the presence of another sound. A tone is masked most effectively by other sounds close to it in frequency. The concept of the critical band holds that masking is done by a narrow band of frequencies in which the masked tone is centered. The effectiveness of this band is not increased by the addition of other frequency components if the level per

cycle is held constant. Actually, tones can also be masked by quite dissimilar sounds if the intensity is sufficiently high. The intensity of sounds, particularly in the region of the test frequency, must not exceed certain levels if masking is to be avoided. It is essential to provide a test environment which enables the measurement of hearing at the zero hearing threshold level which represents normal hearing.

In order to do this it is usually necessary to test within an acoustically treated chamber located in a reasonably

quiet place. Prefabricated test booths and larger chambers are commercially available and are to be preferred. The attenuation characteristics of a prefabricated room are known, so that it is possible with this knowledge to predict whether or not a suitably quiet test environment can be arranged. The earphone cushion contributes some additional attenuation. The factors of threshold levels, masking, and earphone attenuation are taken into account in setting the maximum permissible octave band levels of noise given for each audiometric test frequency in Table II.

Table II

MAXIMUM PERMISSIBLE SOUND PRESSURE LEVELS FOR NO MASKING AT ZERO
HEARING THRESHOLD LEVEL, AND SOME ATTENUATION CHARACTERISTICS

Test freq.	Octave band freq.	Permissible ASA 1951	SFL, zero mask* ISO 1963	Attenuation in decibels			
				Single wall	Double wall	New cups & cush.**	
						(a)	(b)
125	75-150	40	31	27	30	14	12
250	150-300	49	25	39	46	15	13
500	300-600	40	26	49	54	16	10
750	600-1200	40	--	53	60	22	8
1000	600-1200	40	30	53	60	22	8
1500	1200-2400	42	32	56	72	30	8
2000	1200-2400	47	38	56	72	30	8
3000	2400-4800	52	43	56	72	38	14
4000	2400-4800	57	51	56	72	38	14
6000	4800-10 K	62	51	54	68	38	11
8000	4800-10 K	67	55	54	68	38	11

*Permissible sound pressure levels for zero mask shown in the table include the contribution to noise attenuation by the standard earphone cushions.

**Values given here are unpublished research data from the Division of Occupational Health showing in column (a) the average dB attenuation for octave bands of noise provided by two types of commercially available earphone cups with circumaural cushions; values in column (b) represent the attenuation of these circumaural cups and cushions over and above that of standard earphone cushions.

Also given are the estimated attenuations provided by available single wall and by double wall prefabricated test rooms. The permissible levels shown are based on the ASA 1951 hearing threshold level values. The new ISO 1963 levels will require that noise levels be lowered by the number of decibels by

which the ISO and ASA standards differ. New but non-standard types of earphone cups and cushions can provide the additional attenuation indicated in the last column.

The table contains sufficient information to enable the calculation of needs

for an adequate test environment in a particular location where the octave band levels of noise have been measured. The differences between the measured octave band levels of ambient noise in the planned test area and the maximum permissible noise levels for the same octave bands give the amount of attenuation which will have to be provided for test purposes. By noting the amounts of attenuation available it is easily determined whether a single or a double wall room is needed. If the single wall room would provide more attenuation than is actually needed, perhaps acoustic treatment of the test area will be sufficient. If even the double wall

room and the use of the special earphone cups do not furnish enough attenuation, it will be necessary to reduce the ambient noise levels outside the test room by acoustic treatment or other quieting measures.

The minimum size for a test room is 3.5 feet by 3.5 feet by 7.5 feet if the test operator is stationed outside. If the operator also occupies the test chamber, the dimensions must be increased. The test room should be well ventilated and adequately lighted, and it should be carpeted. Temperature should be regulated to a comfortable level.

References

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PRINCIPLES OF NOISE CONTROL

Introduction

With the increased mechanization, use of larger and faster machinery, and the speed up of transportation in the last decade there has also been an increase in noise output. This has resulted in a greater need and demand for noise control, and it has become necessary that the industrial hygienist be familiar with some of the principles involved in the control of noise exposures. General acoustical principles of noise control have been fairly well established; however, the complexities of the industrial noise sources and their environments, in many uses, require empirical solutions. In general, it will not be possible to use "text book" solutions for a specific noise problem because many situations will require a certain amount of experimental work for a satisfactory answer to a particular problem.

It must be emphasized that, in order to control noise, large reductions in energy must be achieved. For example, a reduction of 3 dB requires a 50% reduction in energy, a reduction of 10 dB requires a 90% reduction in energy, and a reduction of 30 dB requires a 99.9% reduction in energy. For this reason noise control is quite often expensive, and it is important to study the problem thoroughly before an attempt is made to reduce the noise.

The first step in the control of noise is to secure adequate quantitative and qualitative information on the extent of the problem. This requires extensive noise measurements and a complete description of the environment. The next step is to compare the measured levels of noise with acceptable criteria for the particular environment. This establishes the amount of reduction which is necessary. When the required amount of

noise reduction has been determined the industrial hygienist must then consider various noise control measures such as engineering design, personnel protection, or limitation of length of exposure. It should be kept in mind that personal protective devices are not a substitute for engineering control.

Plant Design

Since exposure of workmen to industrial noise is becoming more of a problem with our advancing technology, it is essential that preliminary planning be done prior to constructing a new plant or to modernizing an existing plant in order to eliminate or minimize excessive noise.

Selection of Building Site

Several factors should be taken into consideration in the selection of a plant site; one of the most important of these is the existing noise level of the community. A noisy industrial plant should be located in an area that has a high background noise level rather than in a quiet area. Conversely, a church, school or hospital should be located in an area with a low background noise level. Of course, it would be possible to obtain the same net result by locating the building in the center of a large tract of vacant land.

Often, advantage can be taken of the topography and prevailing winds in controlling noise. There is a tendency for sound waves to be deflected upward so it is better to locate a plant on top of a hill rather than in a valley if there is a choice and if there is a possibility of a neighborhood noise problem. Sound waves traveling into the wind tend to be deflected upward while those traveling in the same direction as the wind tend to be deflected downward. In some situations it may be possible to take advantage of this by considering prevailing winds.

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It is also possible to reduce noise by proper landscaping, using embankments, terraces, or shrubbery as sound barriers. These can be used to isolate a building from existing noise or to prevent noise from a building creating a neighborhood problem.

Building Layout

Noisy operations should be isolated from the rest of the work room. When a quiet area such as offices, conference rooms, libraries and similar areas are desired, it is better to locate them away from street noise or other noise sources.

Selection of Work Process

Sometimes the work process can be changed with an appreciable reduction in noise level. Some possibilities are as follows:

- (a) Compression riveting instead of pneumatic riveting;
- (b) Welding instead of riveting;
- (c) Belt drives in place of gears;
- (d) Hot instead of cold working of metals;
- (e) Pressing instead of rolling or forging;
- (f) Avoidance of dropping hard materials during handling.

Choice of Equipment

Serious consideration should be given to procuring new equipment with the lowest possible noise level. Engineering specifications should incorporate noise levels desired and requirements for noise performance data. In most cases, the machinery manufacturer is in the best position to reduce the noise of the machine at its sources with proper design. If there are a number of suppliers of the equipment being purchased, the relative noise outputs of each should be evaluated when considering prices and other factors that determine which product will be chosen. One should consider also how much the

application of noise control measures will add to the cost of a less expensive, but noisy machine.

Reduction of Noise at Source

If at all practical, it is usually more economical to reduce noise at its source rather than to attempt either to reduce noise levels in a large work area or to provide, and supervise the use of, personal ear protective devices for several workers. Furthermore, reduction or elimination of noise at its source affords protection to the immediate operator(s) as well as to other workers in the area. Several general methods for reducing noise are discussed below.

Maintenance

Poor maintenance quite often is the cause of excessive noise from a piece of equipment. Noise may result from worn bearings or worn parts which fit loosely or have excessive play in them, or worn parts which are no longer balanced. Replacement of parts or proper adjustment will help to eliminate the noise. In some cases the covers or safety shields on machines are loose and vibrate with the resultant generation of large amounts of noise, which can be eliminated by properly securing these covers.

Noise is produced by frictional forces generated by grinding and cutting operations and from portions of machines such as clutches and brakes. Some of this noise can be eliminated by proper lubrication of moving parts on the machine and the use of cutting oils or coolants on the materials being handled. The use of sharp and properly shaped cutting tools will usually reduce noise at such operations. The proper maintenance and replacement of materials causing friction, or substitution of other materials in brakes and clutches, may give a reduction in noise. Proper maintenance should be the first consideration in reducing noise from an existing piece of machinery.

Reduction of Driving Forces

Reciprocating motion or unbalanced rotation can produce noise, or it may excite other structural members, setting them into vibration and causing them to radiate noise. The higher the rotational speed the greater the need for precise balancing. It is usually advisable to select structural members with a resonance frequency that does not coincide with the rotational speed.

Increased speed results in greater forces which usually create higher noise levels. Therefore, no machine should be operated at a higher speed than is necessary. It may be desirable to use a larger machine operating at a slower speed rather than a smaller machine at high speed and maximum power.

Impact noise is generated when materials are forged, hammered, sheared, tumbled or peened. Because of the short duration of most impact forces the noise is strongly dependent upon the maximum amplitude of the force. Often the same work can be accomplished by spreading the force over a longer period of time. This can be done in some cases by the use of stepped dies, which produce a number of small impacts rather than one larger impact. Other ways in which this can be done are by the use of a hydraulic press instead of a forge hammer or impact hammer, a rotating shear instead of a square shear, and a hydraulic instead of a mechanical press. Oil films will provide a cushion and thus tend to reduce noise from some cutting or punching operations.

Reduction of Response of Vibrating Surfaces

The response of a surface to a driving force can be reduced by increasing its stiffness, increasing its mass, damping the member, improving its support, or shifting its resonant frequency.

When the frequency of the driving force is equal to the natural frequency of

the member being vibrated, resonance occurs and large surface displacements develop with a resultant increase in noise generation.

The response of a surface to vibration can be reduced by increasing the mass and stiffness. This is particularly true under resonance conditions where it is possible to shift the resonance frequency and reduce the amplitude of vibration.

Vibration damping materials minimize the amplitude of vibration of a noise radiator by converting part of the energy to heat. This is accomplished by the internal friction or mechanical hysteresis of the material as it is stretched and compressed by the vibrating motion of the radiator. This is usually more effective at high rather than at low frequencies.

Under both resonant or non-resonant conditions vibration can be reduced by the proper support of the member. Often, a most important source of sound results from impacts between loosely fastened portions of the vibrating surfaces. If the areas are small, they can be fastened rigidly but if they are large it may be necessary to use rubber or plastic bumpers or supports.

The sound energy generated by a vibrating surface depends on the velocity of surface motion and the area of the radiating surface. In general, any regularly shaped area with one dimension greater than $\frac{1}{4}$ wavelength can effectively radiate sound at the frequency corresponding to that wavelength in air. The effective radiation of low frequency sound is therefore limited to large surfaces while any surface of more than a few square inches can radiate sound at frequencies above 1000 cycles per second. Surfaces radiating low frequency sounds can sometimes be divided into smaller areas thereby reducing their efficiency as sound radiators.

Use of Directionality of Source

Many pieces of equipment radiate more noise in one direction than in others. Usually the equipment can be located so as to take advantage of this difference. The equipment should be located so that the minimum intensity in the sound field occurs at the point of interest. This is helpful in only the near field and will provide very little reduction in the reverberant field. At times some noise reduction can be obtained by directing the main source toward an absorbing surface to prevent the noise from radiating into the remainder of the room.

Reduction of Noise Caused by Fluid Flow

Noise is usually generated if the flow of gas varies irregularly in equipment. This may occur, for example, in an internal combustion engine, from the use of a high speed fan or blower, or from jets of compressed air and steam from air driven tools. Examples of techniques for controlling the noise from such sources are:

- (a) Install proper intake and exhaust mufflers on internal combustion engines;
- (b) Use a large fan operating at a slow speed rather than a small, high speed fan;
- (c) Redesign fan blades to reduce the turbulent flow of air;
- (d) Equip compressed air jets with mufflers or redesign the jet nozzle; and
- (e) Redesign the exhaust parts of those tools which produce a siren type of noise or slow down the speed of operation, if possible.

Reducing the Flow of Noise Energy

This is a very fruitful field for noise control because many sources of noise are small and inefficient sound generators. If this flow of energy can be interrupted and prevented from reaching structural members and panels, which may

be more efficient sound generators than the original source, much of the noise can be controlled.

Solid-borne Transmission

Vibrations can be transmitted for considerable distances, with little attenuation, through solid materials. Once vibration is transferred to a solid building structure, such as a concrete floor, it travels through the floor with a speed of about ten times that of sound in air. If it reaches a flexible partition, a floor or a wall, the vibration may force the partition into oscillation and a large amount of sound may be generated. Therefore, solid-borne sound should be suppressed at its source wherever it is practical. This can be done by providing some break in the transmission path such as by the use of flexible mounts for motors and other types of machinery, a segment of flexible metallic or rubber hose in pipes or electrical conduits, flexible coupling on shafts, a short section of canvas in a ventilation duct, or heavy carpeting, cork tile, or some type of resilient covering to reduce impact transmission to floors.

Massive, rigid partitions like concrete floors and walls provide effective insulation against airborne noise but they offer poor protection against solid-borne vibration. On the other hand, porous materials that are poor insulators of airborne sound can be used to present an effective barrier against the transmission of solid-borne vibration.

Airborne Transmission

Where it is not possible to control noise within a piece of equipment, some other method must be used. It is usually more economical and effective to construct a partial or total enclosure around a machine than to install sound absorbing materials throughout the entire work area involved.

Partial enclosures can be of a number of shapes or designs. They may consist of single panels beside the source, panels on both sides of the source, or tunnels with the work flowing through them. The barrier can be constructed by using plywood, wallboard, sheet metal, or almost any dense material with the requisite mass and strength. Sound absorbing materials should be used on the inside of these enclosures next to the noise source. This type of enclosure will provide protection for the machine operator only if it is located between the operator and the machine. It will produce a shadow effect and give up to 10 to 15 dB protection outside of the enclosure.

In some cases machines or noisy operations can be enclosed except for small access openings, which are treated by the use of short ducts lined with acoustical materials. These enclosures should be made of impervious materials to stop the flow of acoustical energy and should be provided with an acoustical lining to absorb the energy within the enclosure. Properly designed enclosures will give noise reductions of from 20 to 40 dB dependent upon the materials used in the construction.

They do have the disadvantage of interfering with ventilation, handling of materials, and maintenance.

The most common use of sound absorbing materials is, in general, overall noise reduction in enclosed spaces. Sound absorbing material has very little effect on the noise level close to a source, but will give a considerable reduction some distance from the source in the reverberant field. The limit for most practical installations is a reduction of 10 dB. In general, nearly all porous materials are good heat insulators and good sound absorbers as well. Nevertheless, they are usually poor sound insulators. Porous materials or other types of acoustical treatment can reduce the level of the noise transmitted into a room; but they do not provide the most effective means for insulation against outside noise.

Sound absorbing materials are usually porous and may be made of vegetable or asbestos fibers, glass or mineral wool. They are available in a number of forms including blocks, panels or blankets which can be fastened to the walls or ceiling, and space absorbers, which can be suspended from the ceiling.

Introduction

The first step in any noise control problem is to obtain adequate quantitative and qualitative information on the extent and magnitude of the problem. First, existing noise conditions must be defined in terms of noise spectrum and complete information must be obtained on the environment in which the noise exists. The next step is the comparison of the noise spectrum with the appropriate criteria in order to establish the magnitude of the problem. A definitive picture of the severity of the noise problem can be obtained by superimposing spectral plots of existing noise conditions upon applicable noise criteria, as shown in Figure 1. It would be wise to consider that all noises that exceed the criteria warrant consideration for engineering control. The amount of noise reduction necessary is the amount that the noise spectrum exceeds the criteria in each of the frequency bands.

The next step in an effective control program is the definition of the predominate offending noise sources and their characteristics. The definition of the sources and environmental characteristics are necessary in order to select appropriate noise control techniques.

It is the intent in this section to discuss the basic types of treatments useful for the general types of noise problems encountered in industry and to outline techniques for designing and applying these in light of their capabilities and limitations. It is not the intent in this section to design a series of noise control devices to solve individual noise problems associated with industry. Such an undertaking is impractical because of the variations

in noise sources, equipment types, mountings, noise control requirements, background levels, environmental conditions and other special requirements of a particular problem. If the industrial hygienist understands the basic principles of acoustics, he can apply these to a specific problem. He should understand that some experimental procedure is normal in the development of controls for industrial noise problems.

Acoustic Absorption

Noise reduction through the use of acoustic absorption techniques is by far the most common and probably the most predictable of the various approaches to noise control. Acoustic absorbing materials are not intended as "sure-fire" remedies for all sound reduction problems. They are primarily useful in preventing noise reflections and, when placed on walls and ceilings of an enclosure, they achieve noise reduction by preventing repeated reflections of noise about the enclosure. In general they are not well suited to shielding an area from noise being transmitted from the outside.

The maximum theoretical effect on interior noise levels achievable by treating the bounding surfaces of a room of normal dimensions, is to reduce sound levels to the value which would be realized if the source were operating in an open environment. In some instances this may amount to as much as 6 to 10 dB. The treatment will have no effect on reducing the sound power radiated from noisy machinery; and noise levels near the equipment will remain the same. In order to get near field noise reduction with absorbing material, it must be placed in close proximity to the noise source in order that sound energy may be absorbed before it radiates into the open environment of the room. In such applications the material is usually used in conjunction with partial or total barriers.

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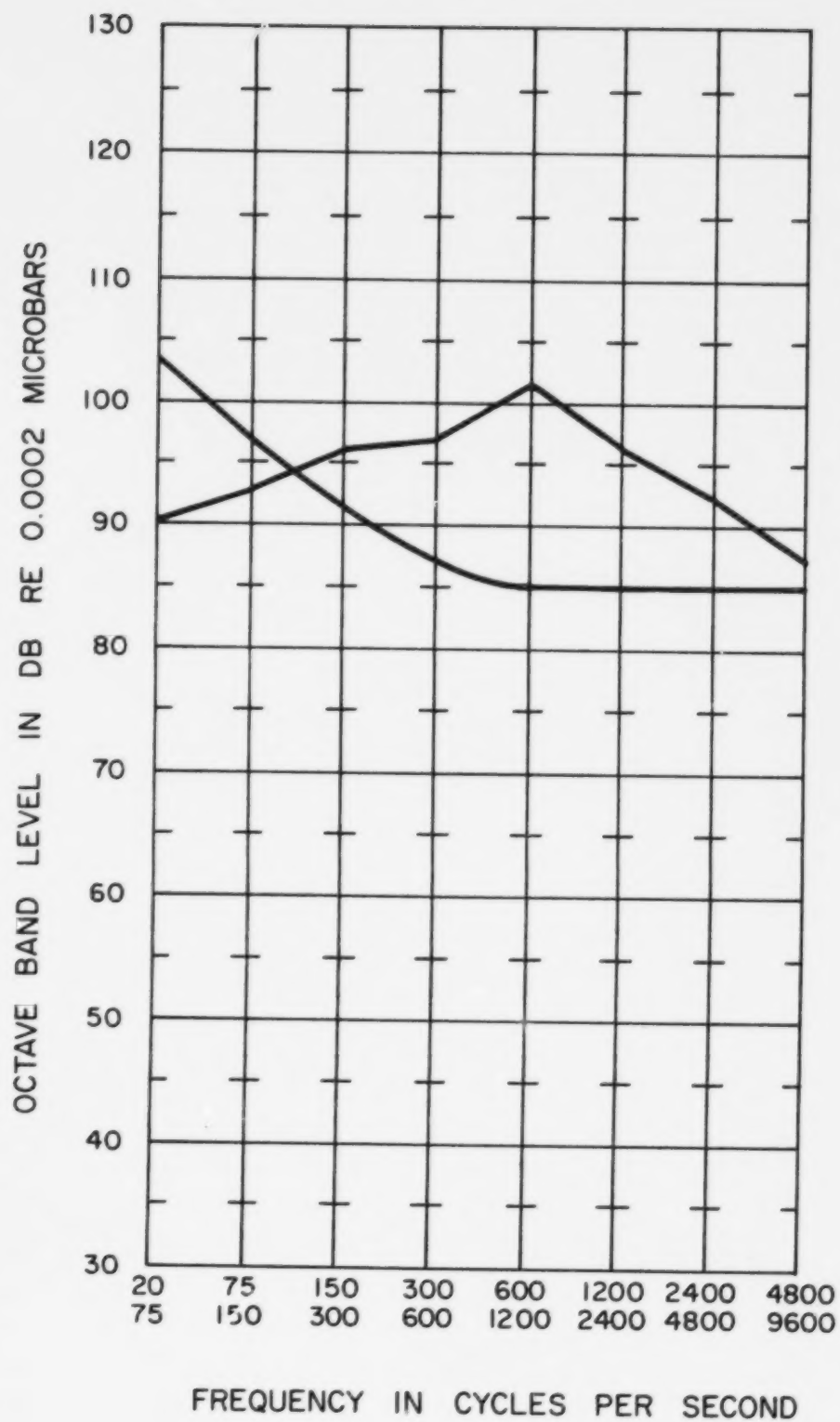


FIGURE 1. PLOT NOISE DATA AND CRITERIA

Sound is absorbed by some mechanism which converts the sound into other forms of energy and ultimately into heat. Most manufactured materials depend largely on porosity for their absorptivity and many of the materials have a multitude of small, deeply penetrating, intercommunicating pores. The sound waves are propagated into these pores where a portion of the sound is converted into heat by friction and viscous resistance within the pores and by vibration of the small fibers of the material.

The efficiency of a material in absorbing acoustic energy at a specified frequency is given by its absorption coefficient at that frequency. This quantity is the fractional part of the energy of an incident sound wave that is absorbed (not reflected) by the material. Since the sound absorption coefficient (α) varies with frequency the value of α is usually determined at 125, 250, 500, 1000, 2000, and 4000 cycles per second. The unit sabin is used to measure the sound absorption of a surface; it is the equivalent of one square foot of perfectly absorptive surface. A surface area, S , that has an absorption coefficient of α has a total absorption of $S \times \alpha$ sabins.

Another term that is often used is the noise reduction coefficient (NRC). This refers to the average coefficient of a specific material to the nearest multi-

ple of 0.05, of the absorption coefficient at 250, 500, 1000, and 2000 cycles per second. It is usually better to select a material on the basis of the absorption characteristics best suited for a particular noise rather than by the average sound absorption of a material.

A convenient means for predicting the effectiveness of proposed absorbing treatment is the calculation of noise reduction that such a treatment would provide. The far field noise reduction at a given frequency can be expressed in terms of total room absorption as follows:

$$NR = 10 \log_{10} \frac{A_1}{A_2}$$

A_1 = Total room absorption before treatment in sabins

A_2 = Total room absorption after treatment in sabins.

An example of the computation of noise reduction for the use of acoustical absorption materials would be made as follows:

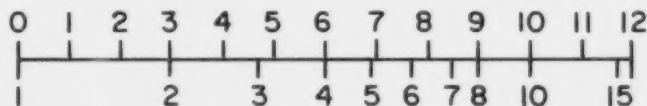
A room 20' x 40' x 10' with plastered ceiling and walls has a sound absorption coefficient, α , of 0.03 at 1000 cycles per second. For the floor, α = 0.04 at the same frequency. The equipment in the room has an absorption of 50 sabins. The ceiling is to be treated with a material having an α of 0.75 at 1000 cycles per second.

	Surface Area (S) Square Feet	Absorption Coefficient (α)	Units of Absorption Sabins
Floor	800	0.04	32
Walls	1200	0.03	36
Ceiling (before treatment)	800	0.03	24
Equipment			50
Total absorption before treatment			142
Ceiling (after treatment)	800	0.75	600
Total absorption after treatment (600 + 32 + 36 + 50) = 718			

$$NR = 10 \log_{10} \frac{A_1}{A_2} = 10 \log_{10} \frac{142}{718} = 10 \times 0.7 = 7 \text{ dB}$$

A graphical technique for solving the noise reduction equation is given below:

DECIBEL REDUCTION



ABSORPTION RATIO $\frac{A_2}{A_1}$ 0

The reverberation time can be helpful in some situations in determining whether additional sound absorption would be effective, or in determining the amount of sound absorption already present in a room or enclosure. The reverberation time is the time required for a specified sound to die away to one-thousandth of its initial pressure, which corresponds to a drop in sound pressure level of 60 dB.

Reverberation time (t_{ec}) =

$$\frac{0.049 V}{S[-2.30 \log_{10}(1-\bar{\alpha})]} \text{ seconds}$$

or, when $\bar{\alpha}$ is small compared to unity, the equation becomes:

$$t_{ec} = \frac{0.049 V}{S \bar{\alpha}} \text{ seconds}$$

Where:

V = room volume in cubic feet

$\bar{\alpha}$ = average absorption coefficient for the room and its contents

S = total exposed surface area, square feet

In many industrial areas it is impractical to calculate total absorption, and in these areas the measurement of the reverberation time can be used to provide this figure. Rewriting the reverberation time equation gives the following:

$$\bar{\alpha} = S[1 - e^{-r}]$$

$$\text{where } r = \frac{0.049 V}{S \cdot t_{ec}}$$

or, when the average absorption coefficient is low (less than about 0.3) $\bar{\alpha}$ can be approximated from:

$$\bar{\alpha} = \frac{0.049 V}{t_{ec} \cdot S}$$

Using the values for total absorption of a room, one can then calculate the required amount of total absorption for any given or desired noise reduction by rewriting the noise reduction equation as:

$$A_2 = A_1 10^{NR/10}$$

The above equations are limited to far field levels, i.e., areas where reverberant effects are significant, rather than directly at the machine. It must be recognized that these equations are approximate, and limited to rooms of normal dimensions and shapes.

Sound Transmission

Another factor that has to be considered in noise control is the sound transmitted through walls, floors, enclosures, etc. The reduction in sound energy is generally expressed as transmission loss in decibels. The transmission loss is equal to the number of decibels by which sound energy, incident on a partition, is reduced in transmission through it.

The transmission of sound through a rigid partition, such as a brick, concrete, or solid wall, is accomplished principally by the forced vibration of the wall; that is, the entire partition

is forced into vibration by the pressure pulsations of the sound energy against it.

The average transmission loss of a rigid partition increases about 4 or 5 dB each time its weight is doubled. Transmission loss also increases as frequency is increased. Values of transmission losses are given in various textbooks and a good reference is Sound Insulation of Wall and Floor Construction, Building Materials and Structures Report BMS 144, National Bureau of Standards. This publication lists the transmission loss for the more common types of wall, floor, and ceiling construction, doors and windows. Figure 2 shows the transmission losses for some typical wall structures.

When sound is transmitted through a porous material, a portion of the sound energy is lost in the form of heat due to the motion of the air within the pores of the material; in non-rigid porous materials (such as mineral wool) some energy is lost as a result of the motion of the component parts of the material. These losses are primarily responsible for the sound insulation provided by porous materials. If the material is uniform, the fractional loss of sound through the first inch of a porous blanket is about the same as the fractional loss through the next inch. In general, the transmission loss provided by a uniform porous material is directly proportional to the thickness of the material, whereas for a homogeneous non-porous partition the transmission loss increases as the logarithm of the mass. It is possible to select a porous partition thick enough for its transmission loss to be as long as that given by the mass law, but it will be very thick. Rock wool, for example, with a density of 5 pounds per cubic foot, has an average transmission loss of 2.2 dB per inch. A 16 inch thick batten will have a transmission loss of 35 dB. This is the same loss as given by the mass law for a wall of 7 pounds per square foot area density.

The results of attenuation measurements on non-rigid porous materials show that such materials, if used by themselves as partitions, do not provide a large amount of sound insulation unless the partition is exceedingly thick. Such materials are good sound absorbers, good heat insulators, but poor sound insulators.

The fraction of incident sound energy transmitted through a partition is called its transmission coefficient (T). It is related to the transmission loss of a partition by the equation:

$$T.L. = 10 \log_{10} \frac{1}{T} \text{ dB}$$

The boundaries of most rooms or enclosures are constructed of a number of sections having different areas of varying transmission coefficients. If it is assumed that each element of construction has sound of the same level incident upon it, the average transmission coefficient $\bar{T}$ is given by:

$$\bar{T} = \frac{T_1 S_1 + T_2 S_2 + T_3 S_3 \cdots T_n S_n}{S} = \frac{T}{S}$$

Where T_1 , T_2 , T_3 , and T_n are the transmission coefficients of the different parts of the boundary; S_1 , S_2 , S_3 and S_n are their corresponding surface areas; S is the sum of all these areas; T is the transmittance.

The transmittance and the total number of units of absorption in a room are the principal factors in establishing a figure of merit for the noise-insulative properties of its boundaries. Such a rating is given by the noise-insulation factor of a room. This factor is expressed by:

$$\text{Noise-insulation factor} = 10 \log_{10} \frac{A}{T} \text{ dB}$$

An example of the uses of this formula is given below to illustrate the importance of eliminating small areas which have relatively large transmission coefficients if good noise insulation is required. Consider the same room used in the example under sound absorption.

	Area Sq. Ft. (S)	T.L. dB	τ	τS
Ceiling - 4" concrete slab plus 1" acoustical tile	800	50	0.0000100	0.0080
Walls - 4" cinder block with plaster both sides	1200	45	0.0000320	0.0384
Floor - 4" concrete slab plus floor covering	800	50	0.0000100	0.0080
3/16" glass windows	60	28	0.0016	0.0960
Two 1½" hardwood doors, close fit	36	20	0.0100	0.3600
Total transmittance				0.5104

$$\text{Noise insulation factor} = 10 \log_{10} \frac{A}{T} \text{ dB} = 10 \log_{10} \frac{142}{0.5104} = 24.4 \text{ dB}$$

or with additional sound absorption

$$\text{Noise insulation factor} = 10 \log_{10} \frac{A}{T} \text{ dB} = 10 \log_{10} \frac{718}{0.5104} = 31.5 \text{ dB}$$

If the windows were replaced by double windows with a transmission loss of 40 dB ($\tau = 0.0001$), the noise insulation factor would be increased to 32.3 dB. On the other hand, if the windows were open ($\tau = 1.0$), the noise insulation factor would be only 10 dB. It is obvious from these examples that little would be gained by an increase in the insulation value of the walls since most of the sound is transmitted through the windows and doors. Also it should be pointed out that there should be no openings in enclosures around doors, services, etc. In the situation above where double windows were used, if there had been an opening of 26 square inches, this would have permitted the transmission of as much sound energy as the balance of the room even though this represents only 0.006% of the area.

Control of Noise in Ventilation Ducts and Conveyor Systems

Conveyor systems and ventilation ducts are often important transmission paths for noise entering or leaving an enclosure.

Various materials are available for lining these ducts in order to attenuate sound traveling along them. The sound attenuation can be calculated as follows:

$$\text{Noise Reduction (NR)} = \frac{12.6a^{1.4}P}{A} \text{ dB/ft}$$

Where:

a = absorption coefficient of the lining material at the frequency of interest

P = perimeter of duct in inches

A = cross-sectional area of duct in square inches

This formula has been found to be accurate, with a possible error of 10%, for ducts having cross-sectional dimensions in the ratio of 1:1 to 2:1, for absorption coefficients between 0.20 and 0.40, and for frequencies between 250 and 2000 cycles per second.

In ventilating systems the motor and fan are usually the predominating source

of noise. This noise is transmitted through the air and solid materials. Usually all frequencies will be present, but there may be a peak associated with the blade frequency, which can be calculated as follows:

$$\text{Blade frequency} = \frac{(\text{rpm})(\text{Number of blades})}{60} \text{ cycles/sec.}$$

Increasing the fan speed increases the total noise level it produces; for a given fan each doubling of the rpm raises the total noise level approximately 15 dB.

Changes in duct size, plenums and bends will all reduce the noise level. For a complete discussion of this subject consult the Guide and Data Book of the American Society of Heating, Refrigerating and Air-Conditioning Engineers.

There are available a number of sound stream absorbers designed to replace sections of ventilation ducts. These are of various configurations using, in some cases, both wall absorption and reduction due to bends in the noise path. The manufacturer will normally have data on noise reduction and pressure loss for stated air flows so these units can be purchased readily for specific jobs with a fair degree of assurance that they will perform satisfactorily.

Isolation of Machinery Vibration

Quite often if machinery is mounted rigidly to the supporting structure, vibration is transmitted to other areas, such as partitions, that radiate sound efficiently. In many vibration problems substantial benefit can be derived from mounts which yield principally in the vertical direction. The effectiveness of a vibration mount for reducing vertical motion is given approximately by the expression

$$T = \frac{1}{\left(\frac{F}{f}\right)^2 - 1}$$

Where:

T = transmissibility

F = disturbing frequency

f = resonant frequency of the mount

The system is effective in isolating vibration only when F is at least two times f. The smaller f is, compared to F, the better the isolation. When T is less than 1, the mounting system will be beneficial. The percentage reduction in vibration is given by the equation

Vibration reduction = 100 (1-T) percent

The resonance frequency f of a vibration mount can be computed in the following way:

$$f = \frac{1}{2\pi} \sqrt{\frac{K}{M}}$$

Where:

K = stiffness of mounts in lb/ft.

M = mass in slugs of the equipment or

$$f_s = \frac{188}{\sqrt{d}}$$

Where:

d = static displacement of the mounting system in inches

Conclusions

Each noise problem is unique. Many noise problems can be solved from an evaluation of the environment, by proper use of available criteria or guidelines and by use of available information on noise control. The job does not end with the design of the noise control measures. Performance of the controls must be checked after installation and modifications made if needed.

PERSONAL PROTECTION FROM NOISE

Noise control measures applied at the source or along the transmission path provide the most effective means of eliminating a potential hazard to hearing. When such measures are impractical or economically unfeasible, the needed noise reduction may be gained through the use of personal ear protectors. Personal ear protectors can be classified into four basic types according to their position relative to the ear. These are:

- (1) **Earplugs:** These devices are inserted in the ear canal and remain in place without any additional support.
- (2) **Semi-insert Plugs:** These devices close off the entrance to the ear canal without actually being inserted into the canal. They are held in place by a headband. Semi-insert plugs are not generally used for ear protection against noise but rather as part of a communications system. For this purpose there is a small receiver of the hearing aid type contained in each plug.
- (3) **Earmuffs:** These devices cover the entire outer ear (pinna) and are held in place by a spring headband, helmet, or some other type of headcovering.
- (4) **Helmets:** Helmets cover most of the head surface and either through a close fit or through integral earmuffs or other types of built-in earpieces supply hearing protection against noise. In addition to ear protection, helmets are usually designed to safeguard the wearer against bump, crash, and cold-type injury. Another requirement for military helmets would be ballistic protection.

Every ear protective device, irrespective of its type, must comply with the following six requirements:

I. Sound Attenuation: The extent to which an ear protector can furnish noise reduction, and therein hearing protection, is directly related to its sound attenuation properties. The greater the sound attenuation capability of an ear protector, the greater its ability to provide hearing protection against a harmful noise. The attenuation characteristics of ear protectors are generally determined by means of a "threshold-shift" procedure. In this procedure, hearing threshold levels for different pure tone frequencies are measured for individual listeners wearing the ear protector under study and then redetermined for the same listeners when no ear covering is worn. The resultant threshold shifts or differences in decibels between thresholds obtained with and without the ear protector in place at the various test tone frequencies serve to show the attenuation characteristics of the protective device. The threshold shift data for at least ten trained listeners, each of whom is tested under the above described conditions at least on three separate occasions, are usually averaged to provide reliable estimates of sound attenuation for a given ear protector. As determined in this fashion, sound attenuation measurements reported for selected earplugs, earmuffs, and helmets are summarized in Table I.

The attenuation values shown for earplugs and earmuffs are fairly equivalent; apparent differences between the two indicate earplugs to be better suppressors of low frequency sounds, but poorer high frequency suppressors. The helmets typically have attenuation values which are equal to or greater than the earplugs and muffs at the high frequencies. On the other hand, helmet attenuation for the low frequency sounds is comparatively poor. Cotton plugs, in contrast

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Table I

MEAN SOUND ATTENUATION (IN dB) OF VARIOUS EAR PROTECTIVE
DEVICES AT DIFFERENT FREQUENCIES

Type	Frequency (in cycles per second)								
	125	250	500	1000	2000	3000	4000	6000	8000
<u>Earplugs</u>									
1	25	24	25	28	36	37	34	40	37
2	29	29	31	30	32	40	45	45	41
3	25	23	25	29	35	41	40	39	36
4	21	20	22	26	37	40	43	44	39
<u>Earmuffs</u>									
1	12	20	30	38	40	41	45	43	38
2	19	23	36	36	31	41	41	45	35
3	22	26	32	40	41	44	48	42	41
4	18	25	35	41	37	38	39	33	30
<u>Helmets</u>									
1	8	10	23	25	38	50	50	50	44
2	8	5	21	21	35	43	44	46	42
3	5	12	15	23	40	42	52	53	55
Cotton	5	6	8	9	13	15	13	14	16
Wax (impreg- nated) -		20	25	29	35	42	46	39	35
Glass - wool -		7.5	11.0	13.9	26.5	28.7	26.3	28.7	31.0
<u>Combination</u>									
Earplug(1) and Ear-muff(2)	37	35	40	40	39	48	51	48	40

to all other ear protectors, show little attenuation for all frequencies. However, cotton impregnated with wax or plugs made from glass-down material can cause significant reduction in sound transmission. These latter items are of value for one-time use.

With the exception of cotton plugs, the attenuation capabilities of the ear-plugs, earmuffs, and helmets described in Table I would be sufficient to reduce many noise conditions found in industry to safe exposure levels. Should it be required, still greater suppression of sound can be gained by wearing ear protectors in combination, e.g., earplugs and earmuffs, earplugs and helmets. Table I shows the sound attenuation which results from wearing a set of earplugs and earmuffs together. Note that the combined attenuation at the various frequencies is less than the sum of the individual attenuation values for the two items. This is due to the fact that the sound energies needed for threshold response when wearing the combination are intense enough to enter the ear directly via bone conduction, thus bypassing the obstructed air conduction pathway into the ear.

II. Comfort: Ear protectors must not be too uncomfortable since, if they are, they will not be worn by the user. Some of the apparent discomfort caused by an ear protector may be nullified if the noise conditions are quite excessive and represent a clear hazard to hearing. Given less intense but still potentially harmful noise conditions, the user may be less likely to tolerate any discomfort associated with the protector.

Pressure applied by the ear protector on the skin is the most direct cause of discomfort. Reducing total pressure and/or distributing the total applied force over a larger area so as to minimize pressure at any given point will promote comfort. Earplug and earmuff designs are guided, in part, by this principle. Plugs come in a wide range of sizes and have soft, pliable outer

layers to take account of the various sizes, shapes, and contours of the ear canal found in the user population. The sealing cushions of earmuffs make contact with a fairly large area of the skin surface circumscribing the ears and also are composed of a soft material so as to fit individual variations in anatomy. Actually, earmuffs do not pose a fitting problem since their basic dimensions will fit all ears. Because of the large size of the ear cups, however, they may be considered as bulky or cumbersome. Also the large surface area of contact between muff and skin may cause overheating of the skin particularly in hot environments.

Helmets distribute their pressure all around the head, but generate discomfort through their weight and bulk.

III. Toxic Effect: One justification for discarding an otherwise satisfactory ear protector is that it causes a toxic effect on the skin. Fortunately, non-toxicity in ear protector materials is probably the easiest requirement to fulfill. Indeed most of the materials used in their manufacture are chemically neutral.

IV. Speech Communication Interference: The ear protector should be designed to interfere minimally with speech communication if such communication is necessary in the noise situations where the protectors are being worn. Contrary to popular belief, wearing an ear protector under continuous high level noise conditions will actually facilitate the ability to hear voice communications. This is due to the fact that the ear protector, in reducing both the level of speech and noise, creates a condition in which the relationship between the two is more favorable to intelligible reception.

Decided impairment in speech reception will occur, however, if ear protectors are worn continuously in an intermittent or variable noise exposure situation. Special devices have been designed into

ear protectors in an attempt to offset their sound attenuation, should the receiver wish to hear ambient sound more readily. Earmuffs have been made with ports that can be opened or closed depending upon need to hear ambient sound. Plugs have been designed with diaphragms and valves that will transmit a sound unattenuated to the ear provided that it is below a certain intensity level. If this level is exceeded, the diaphragm hits a stop which impedes or attenuates sound transmission to the ear. Unfortunately, these latter devices when in an attenuation state leak sound to the ear, consequently offsetting their ability to provide effective noise protection.

V. Ease of Use and Handling: Ear protectors are more assured of being effective if their application is uncomplicated. More specifically, an ear protector which requires a good degree of precision and effort in its proper usage will probably give poor performance results in the field. Earplugs require more deftness in handling and

use than any other type of protector, which makes them more vulnerable to poorer performance. They have to be individually fitted and faithfully worn to be most effective. Their hygienic care also raises a problem.

Earplugs should only be issued with the plant physician or nurse making the proper size selection and giving instructions as to how they should be worn and cared for. Careful spot-checks to insure their correct use are necessary.

VI. Durability: Ear protectors should be reasonably rugged and resistant to aging. Many factors speed up the aging process such as ear wax, perspiration, humidity, light, and active chemicals contained in the air. Earplugs designed for repeated use are composed of materials which can resist most of these aging factors and can last for two or more years without objectionable changes. Most of the soft resilient materials, however, show a tendency to contract or harden with time or to expand and become soft.

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SELECTED LIST OF REFERENCE SOURCES

Introduction

The following is a list of periodicals and reference texts used in the study of noise and general industrial hygiene by the health worker. The list of literature sources is necessarily selective but is intended to include those journals and texts of greatest usefulness to the workers in this field.

The value of several abstracting journals should be recognized. The Industrial Hygiene Digest is a good source of current information on the health aspects of noise and noise control as well as other topics of interest to the industrial hygienist such as toxicology, engineering, pharmacology and analytical chemistry. Chemical Abstracts, Vol. 56 beginning in January 1962 has added a new section on "Toxicology, Air Pollution and Industrial Hygiene" which includes abstracts of papers on noise of

interest to the industrial hygiene engineer. Public Health Engineering Abstracts has sections devoted to occupational health and air pollution. Standards have been developed in acoustics, mechanical shock and vibration by both the American Standards Association and the International Organization for Standardization, some of which are of interest to the industrial hygienist concerned with noise measurement and control.

The reference sources are classified for convenience, into three general groups, namely: (1) Journals and other periodicals; (2) textbooks and other references; and (3) standards in acoustics developed by the American Standards Association. All references are listed alphabetically according to title to provide a more useful bibliography.

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Standards

The following standards in acoustics have been developed by the American Standards Association (ASA), New York, N.Y., and the recommendations of the International Organization for Standardization (ISO):

ASA-S1.1-1960 - Acoustical Terminology (including Mechanical Shock and Vibration).

ASA-S1.2-1962 - Method for Physical Measurement of Sound.

ASA-S1.4-1961 - Specification for General-Purpose Sound Level Meters.

ASA-S1.6-1960 - Preferred Frequencies for Acoustical Measurements.

ASA-S2.2-1959 - Methods for the Calibration of Shock and Vibration Pickups.

ASA-S3.1-1960 - Criteria for Background Noise in Audiometer Rooms.

ASA-S3.2-1960 - Method for Measurement of Monosyllabic Word Intelligibility.

ASA-S3.3-1960 - Methods for Measurement of Electroacoustical Characteristics of Hearing Aids.

ASA-S3.4- - Procedure for the Computation of the Loudness of Noise (Proposed American Standard).

ASA-S3-W-39 - The Effects of Shock and Vibration on Man (Special Report).

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ASA-Z24.5-1951 - Specification for Audiometers for General Diagnostic Purposes.

ASA-Z24.8-1949 - Specification for Laboratory Standard Pressure Microphones.

ASA-Z24.9-1949 - Methods for the Coupler Calibration of Earphones.

ASA-Z24.10-1953 - Specification for an Octave Band Filter Set for Analysis of Noise and Other Sounds.

ASA-Z24.11-1954 - Method for the Free-Field Secondary Calibration of Microphones.

ASA-Z24.12-1952 - Specification for Pure-Tone Audiometers for Screening Purposes.

ASA-Z24.13-1953 - Specification for Speech Audiometers.

ASA-Z24.15-1955 - Method for Specifying the Characteristics of Analyzers Used for the Analysis of Sounds and Vibration.

ASA-Z24.19-1957 - Practice for Laboratory Measurement of Airborne Sound Transmission Loss of Building Floors and Walls.

ASA-Z24.22-1957 - Method for the Meas-

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ISO-R131-1959 - Expression of the Physical and Subjective Magnitudes of Sound and Noise (Supplement R357-1963 included).

ISO-R140-1960 - Field and Laboratory Measurements of Airborne and Impact Sound Transmission.

ISO-R226-1961 - Normal Equal-Loudness Contours for Pure-Tones and Normal Threshold of Hearing under Free-Field Listening Conditions.

ISO-R226-1962 - Preferred Frequencies for Acoustical Measurements.

ISO-R354-1963 - Measurement of Absorption Coefficients in a Reverberation Room.

ISO-R362-1964 - Measurement of Noise Emitted by Vehicles.

ISO-R389-1964 - Standard Reference Zero for the Calibration of Pure-Tone Audiometer.

IEC-123-1961 - Recommendations for Sound Level Meters.

IEC-177-1965 - Pure-Tone Audiometers for General Diagnostic Purposes.

IEC-178-1965 - Pure-Tone Screening Audiometers.